TM 9-1907

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

BALLISTIC DATA PERFORMANCE OF AMMUNITION

RESTRICTED. DISSEMINATION OF RESTRICTED MATTER.—No person is entitled solely by virtue of his grade or position to knowledge or possession of classified matter. Such matter is entrusted only to those individuals whose official duties require such knowledge or possession. (See also AR 380-5.)

DEPARTMENT OF THE ARMY • JULY 1948

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CHAPTER ONE

INTRODUCTION

1. Purpose

This technical manual is published to make available to using-arm personnel concerned therewith, various technical data on the ballistics and performance of ammunition. The manual is presented as a supplement to other publications on the same subject, and as an additional guide to what may be expected of ammunition under combat conditions.

2. Scope

a. The data collated in this manual give information on exterior and terminal ballistics of aircraft bombs, small-arms bullets, artillery projectiles, and rockets, based on various arguments. Data are also given on the effectiveness of such ammunition in attack on concrete emplacements, armored targets, and entrenched and unshielded personnel. The various theories and analyses of ballistics and of penetration are not discussed, the intent being only to present data obtained from observation of test firings and measurements in army proving grounds.

b. Briefly stated, ballistics is a term referring to the science of the motion of projectiles. It is the study of all the various forces, controllable and uncontrollable, which govern the movements of projectiles. Ballistics is divided into two branches – interior and exterior. Interior ballistics treats of the motion of the projectile, and the forces entering therein, while in the weapon. Exterior ballistics treats of the motion, and forces attending, after the projectile leaves the weapon or is otherwise released. Terminal ballistics is that part of exterior ballistics which deals with the forces operating at the end of the projectile's trajectory, that is, at the target.

c. In designing weapons and ammunition, maximum desired terminal effect is the objective followed. A proper balance of many factors is essential to accomplish this purpose. The most important of these factors are terminal velocity; shape, weight, and material used in the projectile; type and weight of explosive charge; and the fuzing system. Thus, a shaped charge used in the "bazooka" is very effective against tanks, but would do only comparatively small damage against concrete emplace-

ments. A general-purpose bomb is exceedingly efficient against certain types of buildings, whereas a semi-armor-piercing bomb will be much more efficient if penetration of more resistant materials is required for destruction of the target. The delay used in a fuze is extremely important, since the position of the projectile with respect to the target at the instant of detonation determines the amount of damage. This is true against personnel and other targets where a certain fragment pattern is desired, as well as against targets such as heavy concrete and armor where, for maximum damage, delay is vital to permit penetration before detonation. To obtain best results, the type of ammunition and the type of fuze must be selected carefully to fit the target. Data on these considerations in performance are given in this manual, to the end of providing a basis for the choice of ammunition to be used.

3. Arrangement

The technical information in this manual is presented largely in the form of tables, charts, and diagrams, and is divided as follows:

a. Chapter 2, Bombing, provides data on aircraft bombs, and covers various arguments in ballistics, fuze function, blast effects, fragment damage, and penetration of earth, armor, and concrete.

b. Chapter 3, Projectiles, provides terminal ballistic data for artillery ammunition, small-arms ammunition, and rockets, covering fragment damage, attack on artillery, armor, concrete, and log-earth targets.

CHAPTER TWO

BOMBING

Section I. BOMB BALLISTICS

4. General

a. This section provides usable ballistic information on aircraft bombs, the data for the most part being incorporated in charts and tables, and includes the following subjects:

(1) Range versus altitude of release.

(2) Differential effects on range:

(*a*) Effect on range of a 10-mile-per-hour differential wind versus altitude of release.

(*b*) Effect on range of a 10 percent departure from standard ballistic density versus altitude of release.

(3) Striking velocity and angle of fall versus altitude of release.

(4) Trail versus drop.

b. Ballistic functions are charted at true air speeds of 200 and 400 miles per hour, and for 50-mile-per-hour head winds for each of the following:

BOMB, fragmentation, 20-lb, AN–M41 and AN–M41A1 (figs. 2, 3) (100-lb cluster, immediate opening)
BOMB, fragmentation, 90-lb, M82 (figs. 4, 5) (500-lb cluster, immediate opening)
BOMB, fragmentation, 260-lb, AN–M81 (figs. 6, 7)
BOMB, GP, 100-lb, AN–M30 and AN–M30A1 (figs. 8, 9)
BOMB, GP, 250-lb, AN–M57 and AN–M57A1 (figs. 10, 11)
BOMB, GP, 500-lb, AN–M64 and AN–M64A1 (figs. 12, 13)
BOMB, GP, 1,000-lb, AN–M65 and AN–M65A1 (figs. 14, 15)
BOMB, GP, 2,000-lb, AN–M66, AN–M66A1, and AN–M66A2 (figs. 16, 17)
BOMB, LC, 4,000-lb, M56, M56A1, and M56A2 (figs. 18, 19)
BOMB, SAP, 500-lb, AN–M58, AN–M58A1, and AN–M58A2 (figs. 20, 21)
BOMB, SAP, 1,000-lb, AN–M59 and AN–M59A1 (figs. 22, 23)
BOMB, AP, 1,600-lb, AN–Mk 1 (figs. 24, 25)

c. For additional ballistic data on the bombs listed in *b* above, reference should be made to pertinent bombing tables (see par. 4, app.).

5. Charts of Range Versus Altitude of Release

The range-altitude charts in figures 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24 are based on range with no wind, and range with a 50-mile-per-hour head wind. Range as considered in the charts is the distance between the point of impact and the point directly under the airplane at the instant of bomb release. With no wind, the true air speeds and ground speeds are the same (200 and 400 miles per hour). For each set of two curves, a 50-mile-per-hour head wind reduces the ground speed to 150 and 350 miles per hour, respectively. Effects of other head or tail winds may be obtained by interpolation or extrapolation. The following examples show how the chart is used (see fig. 1).

a. Assume the bomb is to be dropped from an altitude of 20,000 feet with a true air speed of 200 miles per hour and no wind. A vertical line is dropped from the intersection of the solid curve (②, fig. 1) for 200-mile-per-hour true air speed and the horizontal line for 20,000-foot altitude of release. The point at which it meets the line at the base of the chart indicates the range. The range at this point is found to be 10,140 feet.

b. If a 50-mile-per-hour head wind (resulting in a ground speed of 150 miles per hour) is assumed, the range for a bomb dropped from 20,000 feet is found from the dotted 200-mile-per-hour curve (①) in the same way as in the first example. The range in this instance is 7,840 feet.

c. In the case of a 60-mile-per-hour tail wind with a 200-mile-per-hour true air speed, interpolation must be employed. The distance between the 200-mile-per-hour and 400-mile-per-hour curves (② and ④) for range with no wind is measured on the 20,000-foot altitude of release line. Since there is a difference of 200 miles per hour between these two curves, and the tail wind is 60 miles per hour, 60/200 or 3/10 of the distance from the no-wind, 200-mile-per-hour curve (②) determines the point from which the vertical line must be dropped to the range line to determine the range. Intersection of the range line with the vertical line from the point of interpolation shows the range to be 12,900 feet.

d. If the wind were a head wind of 60 miles per hour, the interpolation point would be 1/5 the distance between the 200-mile-per-hour curve (②) for no wind, and the 200-mile-per-hour curve (①) corrected for a 50-mile-per-hour head wind. This is so because the 10-mile-per-hour increase of a 60-mile-per-hour wind above the given head wind of 50 miles per hour is 1/5 the difference between the latter wind and no

wind. But the ground speed of a 200-mile-per-hour true air speed wi a 60-mile-per-hour head wind is 140 miles per hour. It is, therefor necessary to extrapolate to the left of curve (①) to find the point fro which to drop a vertical line to the range line. This is done by mea uring to the left (decreasing velocity side) of the 200-mile-per-ho curve (①), corrected for a 50-mile-per-hour head wind, the distan originally determined by interpolation. This range is found to 1 7,280 feet.

6. Charts of Differential Effects on Range

a. Effect on Range of a 10-mile-per-hour Differential Bal listic Range Wind. The differential charts in figures 2, 4, 6, 8, 1 12, 14, 16, 18, 20, 22, and 24 were constructed on the assumption c a constant wind, although in general the wind is not constant at a altitudes. Meteorological observations of winds at different levels ca be averaged to give a mean constant wind, termed the *ballistic winc* that will have the same effect on the bomb trajectory as the actu variable wind. The difference between this *ballistic wind* and the win at release is the *differential ballistic wind.* In the absence of a good valu for *ballistic wind,* it may be assumed that the *differential ballistic win* is 30 percent of the wind at release altitude and in the opposite direction

b. Effect on Range of a 10 percent Departure from Standar Ballistic Density. The difference at various altitudes between th actual air density and the standard air density, expressed as a percentag of standard air density, may be determined by meteorological observa tions. An average of these variable differences gives a result known a the *ballistic density difference* which has the same effect on the trajector as the actual variable percentage density differences. When an accurat ballistic density change is not available, the percentage density change at the ground should be used as an approximate value. This is found b taking as a percentage of the standard density, the difference betwee the actual density at the air field and the standard density for the same altitude, given in table I. Upon obtaining the percentage difference fro standard density, the range effect may be found from the appropriate bomb chart. If the target is not at sea level, the height of the target correction given in the bombing tables should also be employed if it is available.

c. Table of Air Density. The table of air density (table I) gives standard density against altitude in thousands of feet. Standard density is the actual density of the atmosphere in grams per liter at the indicated altitude under standard conditions of temperature, pressure, and humidity.

Table 1. Standard Air Density from Sea Level to 6,000 Feet

Altitude (feet above sea level)	*Standard density* (grams per liter)
0	1.203
1,000	1.166
2,000	1.130
3,000	1.095
4,000	1.061
5,000	1.028
6,000	0.996

7. Striking Velocity and Angle of Fall Versus Altitude of Release

The first of the two charts in figures 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, and 25 give striking velocity and angle of fall versus altitude of release.

8. Trail Versus Drop

The second of the two charts presented in figures 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, and 25, give trail distance as a function of drop, show actual trajectories with respect to axis fixed in the airplanes. From them can be determined how far a bomb dropped from a given altitude will lag behind the bomber.

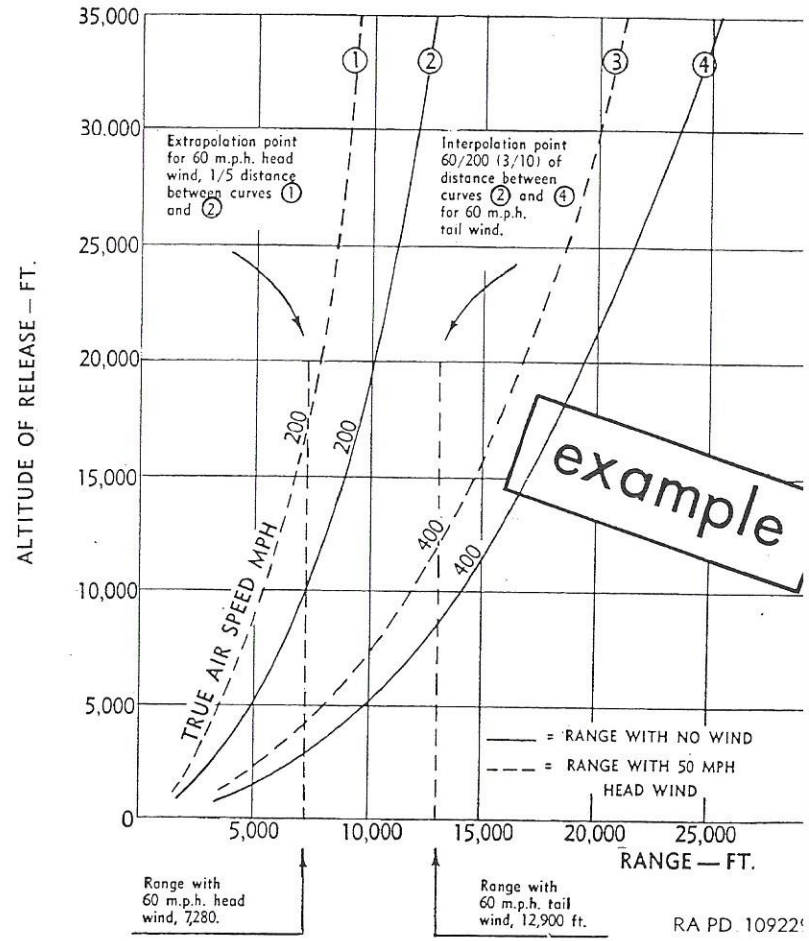


Figure 1. Illustration of interpolation and extrapolation for head and tail wind in determining range by range vs. altitude of release charts.

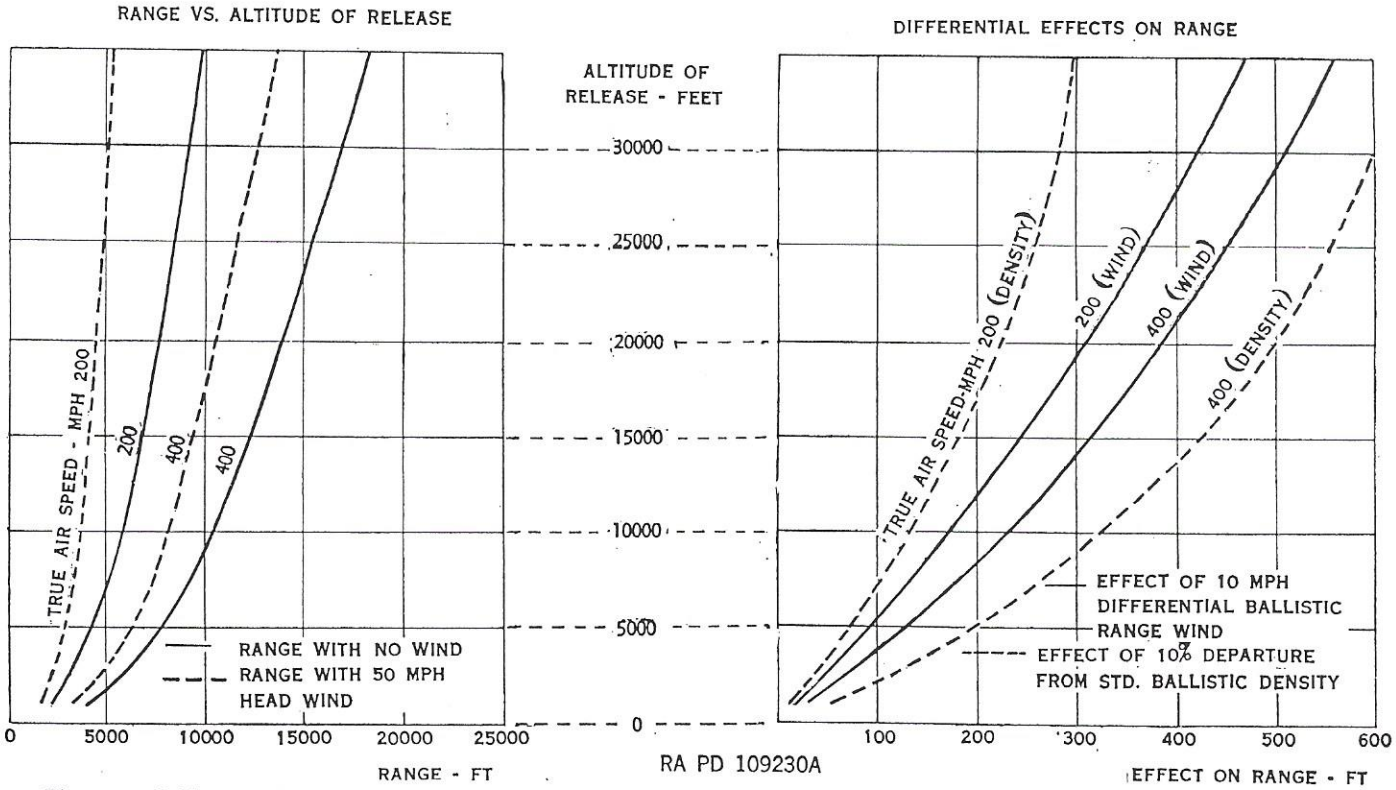


Figure 2. BOMB, fragmentation, 20-lb, AN–M41 or AN–M41A1, in CLUSTER, fragmentation, 100-lb, M1A1 or AN–M1A2, for immediate separation—range-altitude and differential charts.

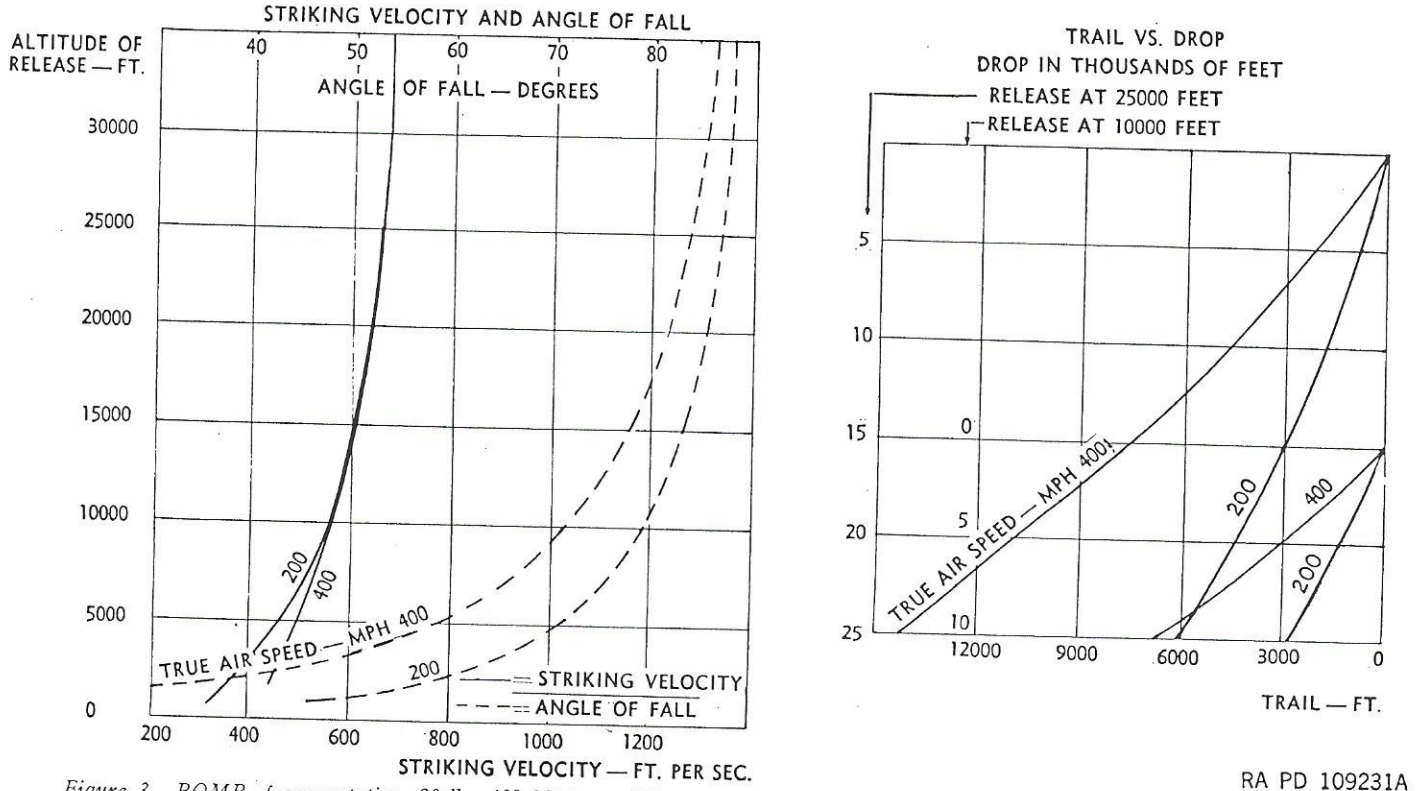


Figure 3. BOMB, fragmentation, 20-lb, AN–M41 or AN–M41A1, in CLUSTER, fragmentation, 100-lb, M1A1 or AN–M1A2, for immediate separation—striking velocity and angle of fall.

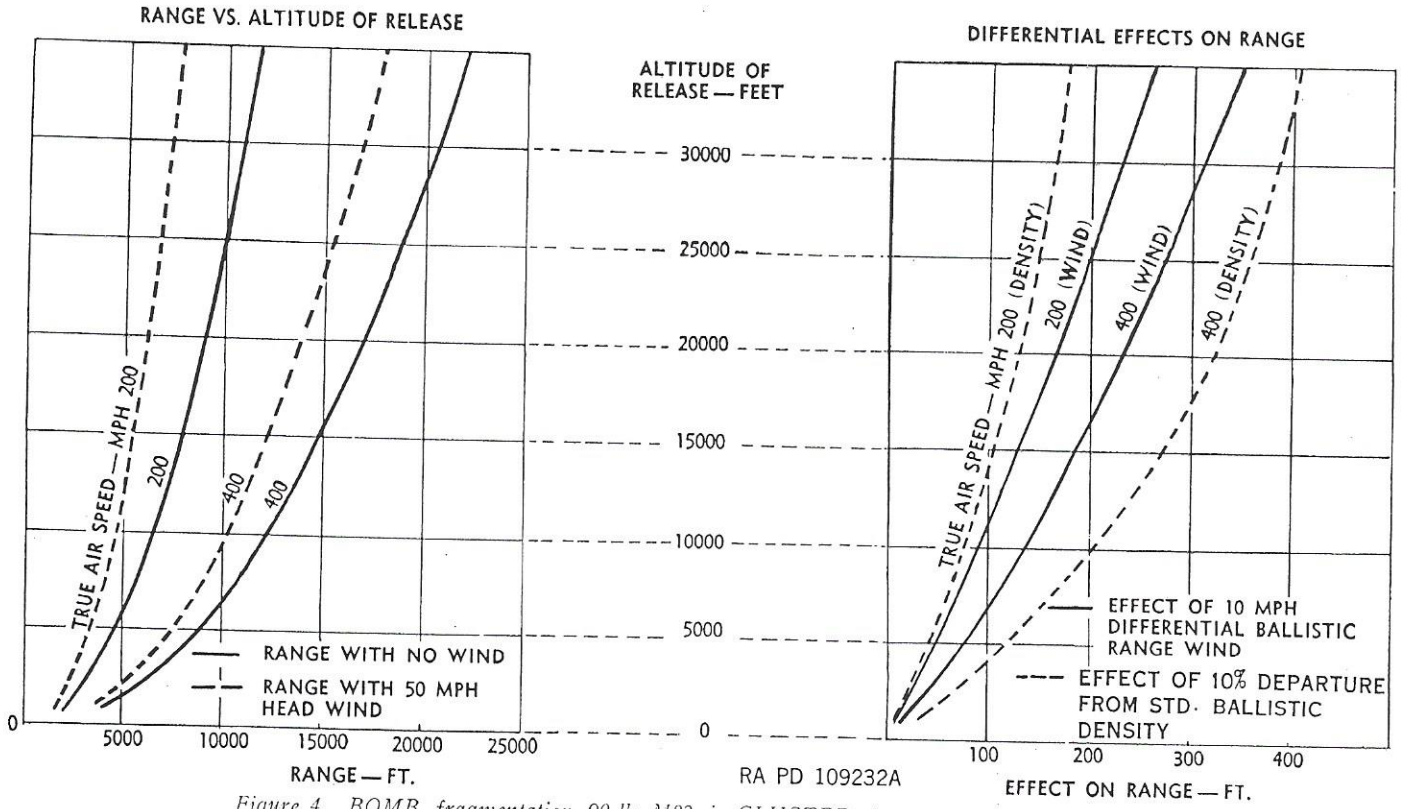


Figure 4. BOMB, fragmentation, 90-lb, M82, in CLUSTER, fragmentation Bomb, M27, for immediate separation—range-altitude and differential charts.

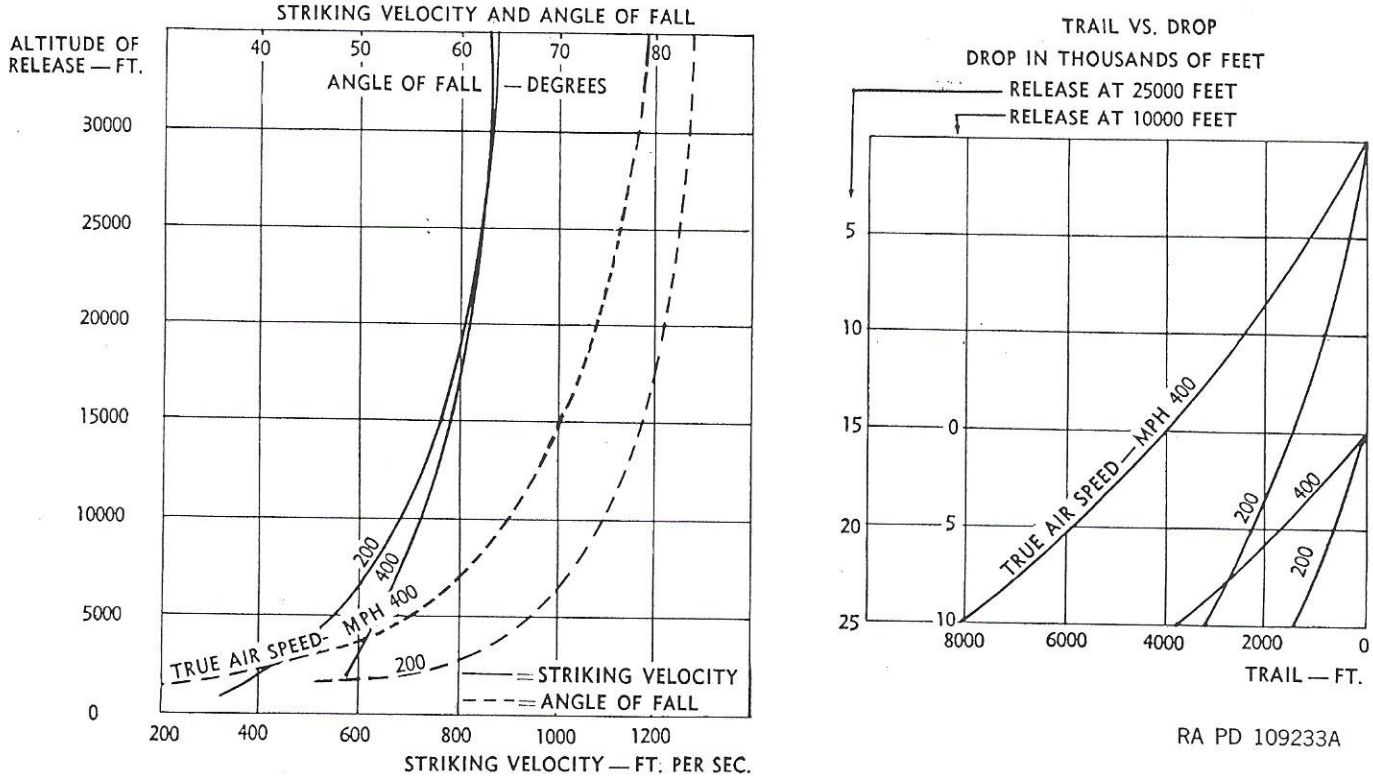


Figure 5. BOMB, fragmentation, 90-lb, M82, in CLUSTER, fragmentation Bomb, M27, for immediate separation—

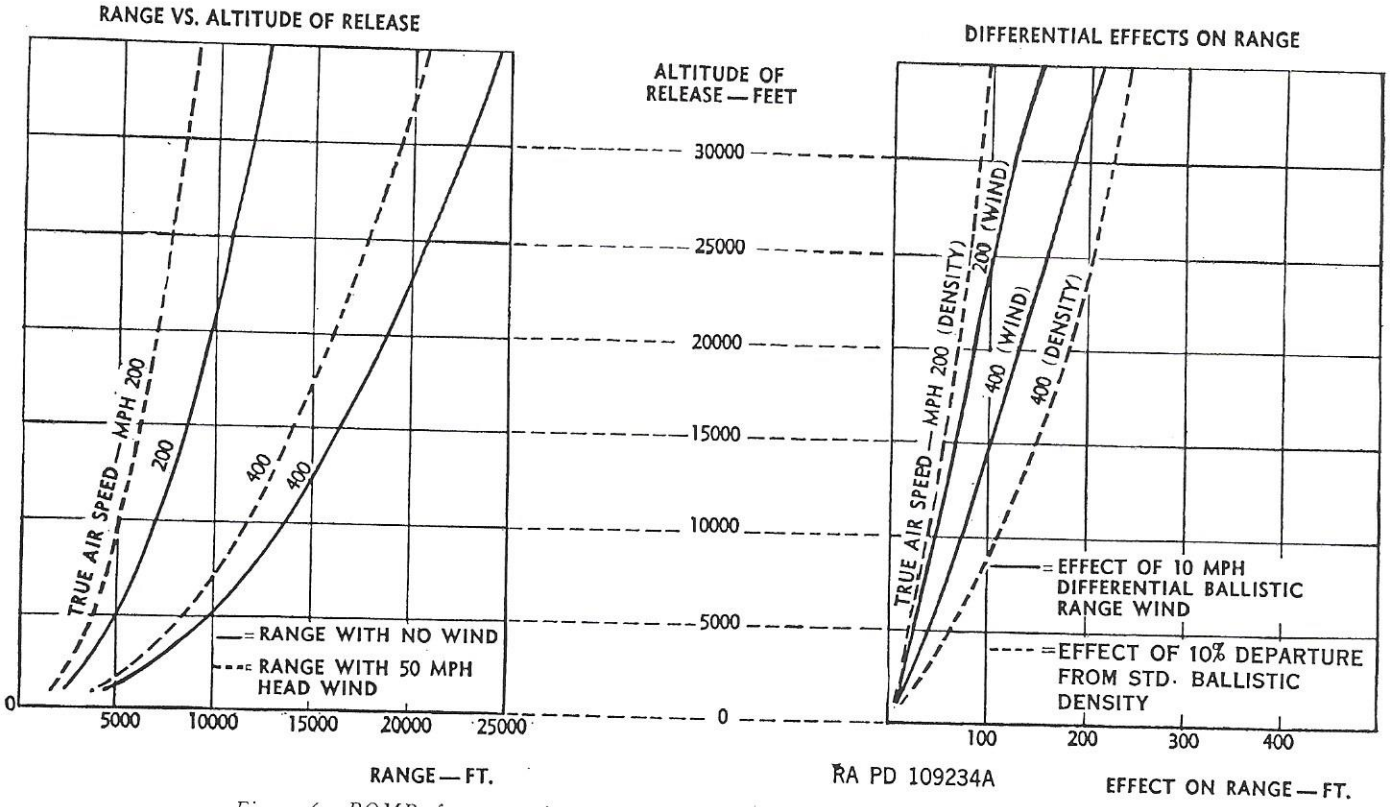


Figure 6. BOMB, fragmentation, 260-lb, AN-M81—range-altitude and differential charts.

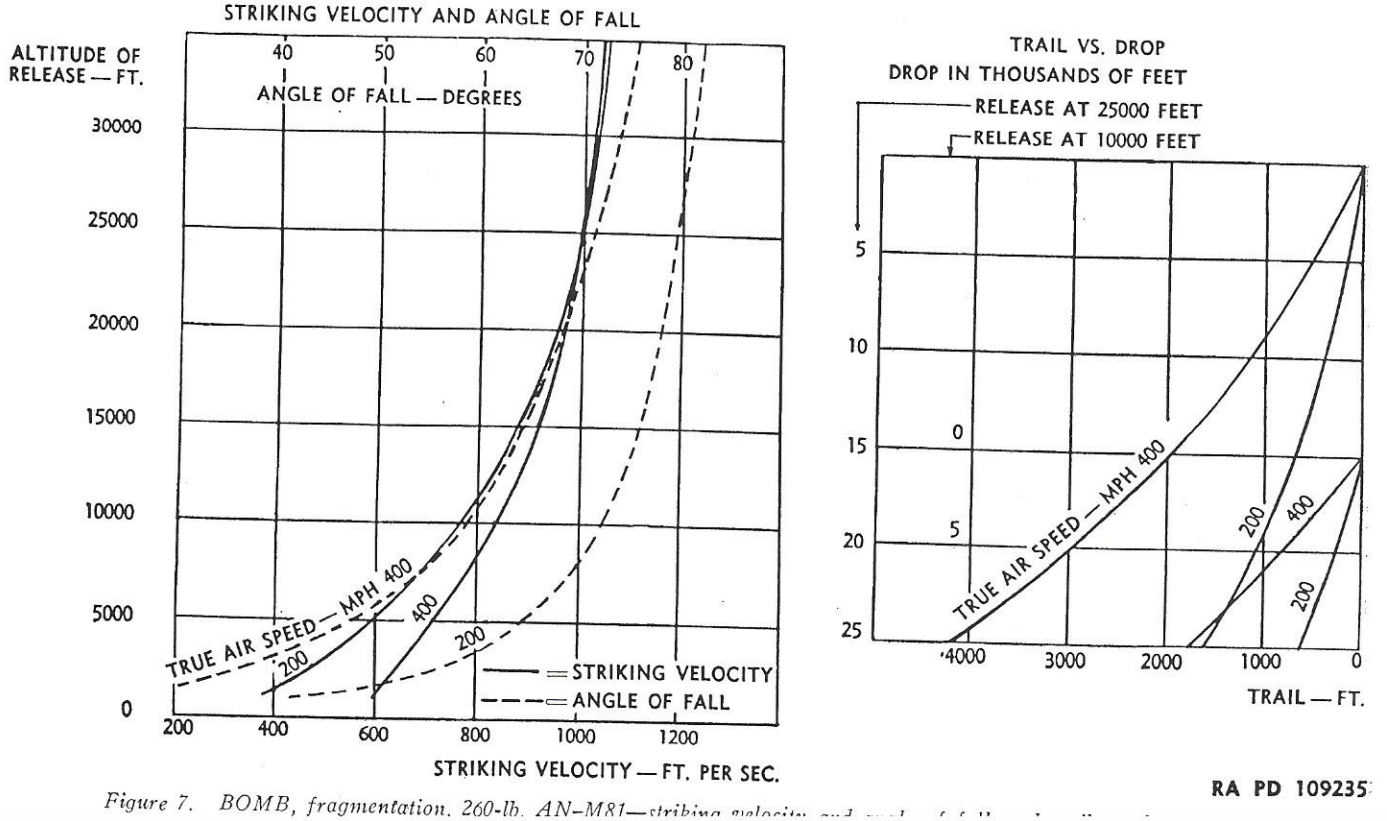


Figure 7. BOMB, fragmentation, 260-lb, AN-M81—striking velocity and angle of fall and trail vs. drop.

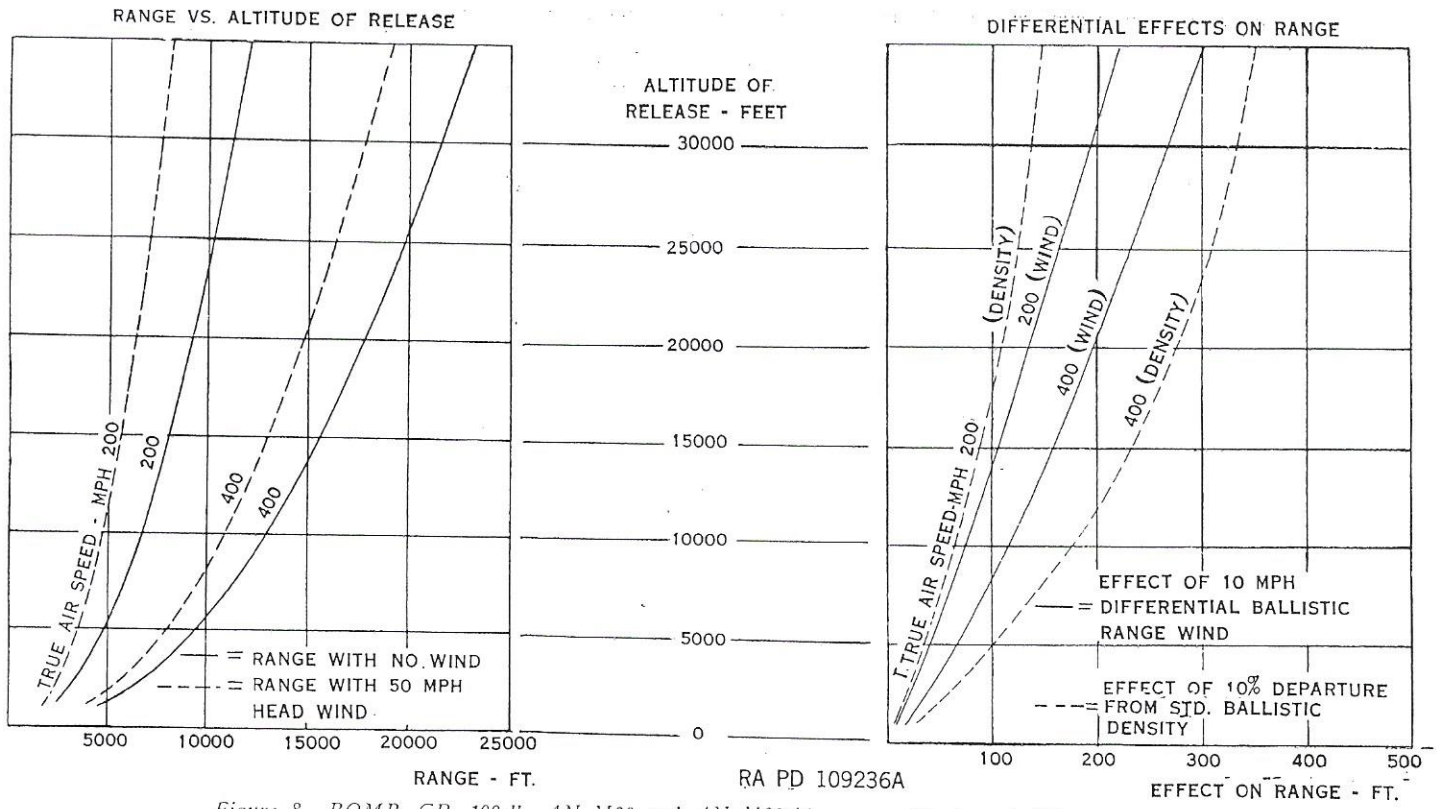


Figure 8. BOMB, GP, 100-lb, AN-M30 and AN-M30A1—range-altitude and differential charts.

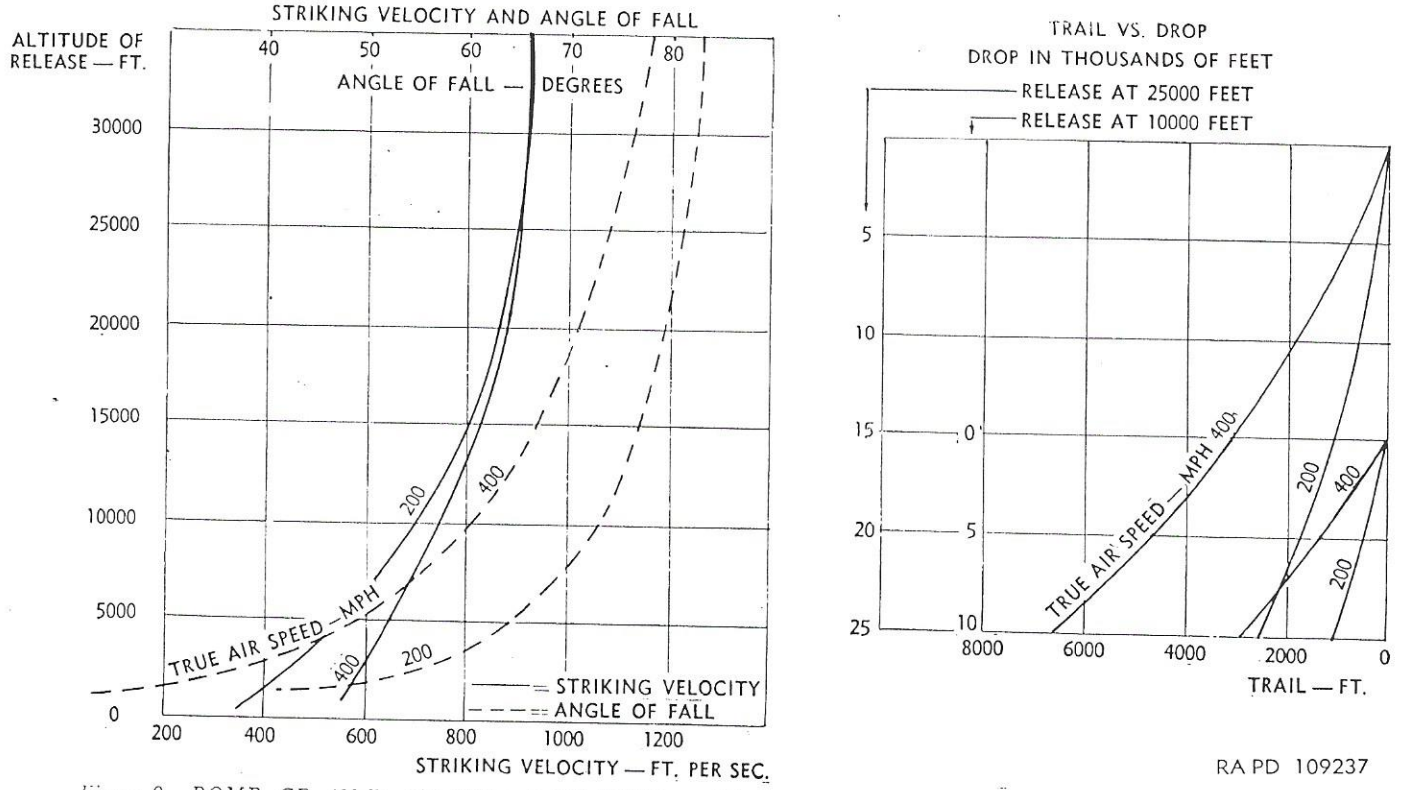


Figure 9. BOMB, GP, 100-lb, AN-M30 and AN-M30A1—striking velocity and angle of fall, and trail vs. drop charts.

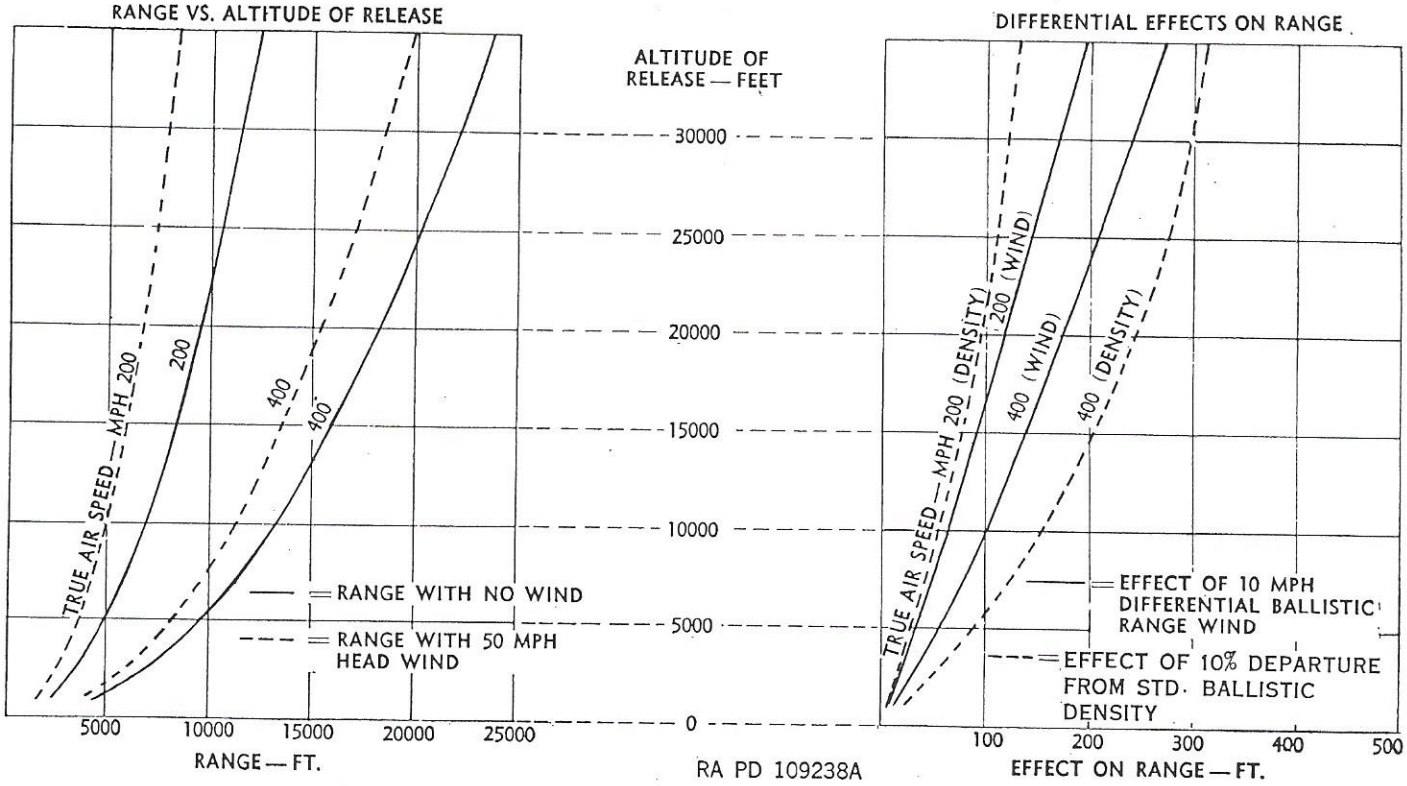


Figure 10. BOMB, GP, 250-lb, AN-M57 and AN-M57A1—range-altitude and differential charts.

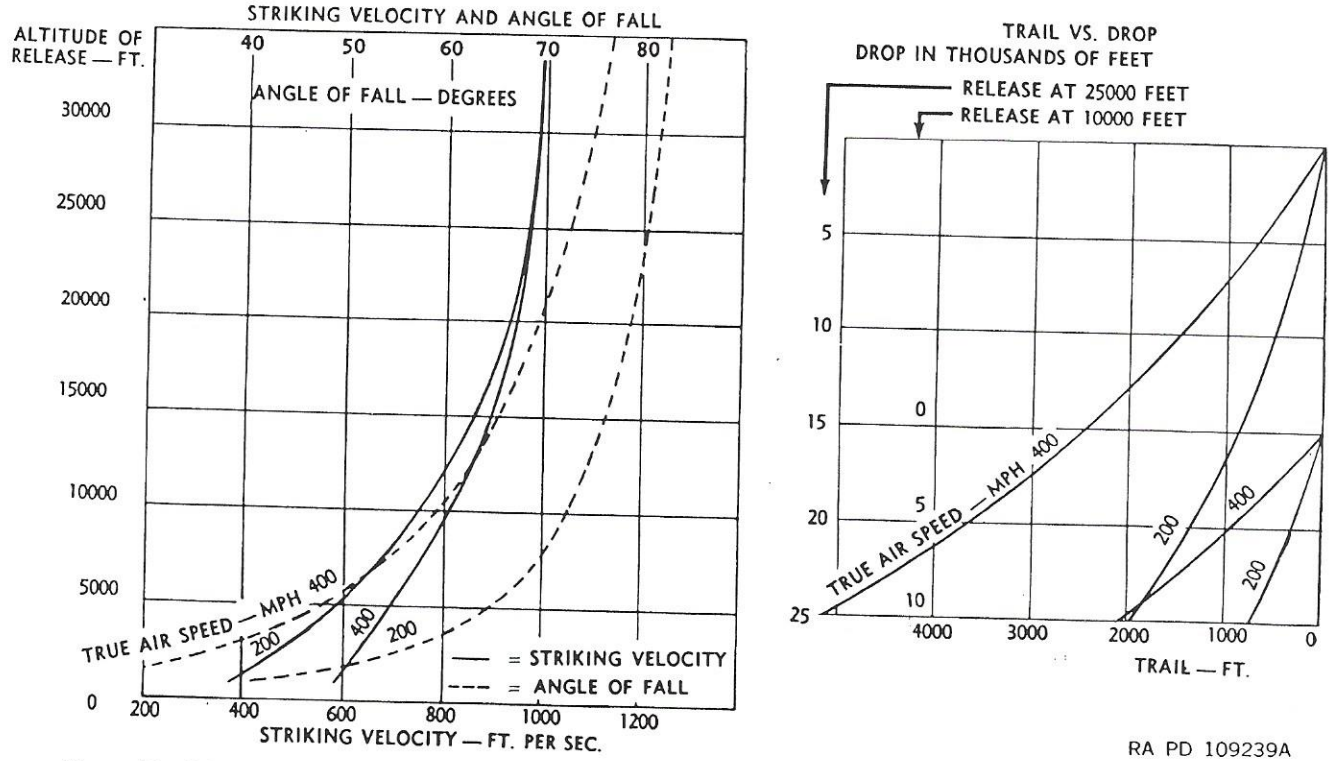


Figure 11. BOMB, GP, 250-lb, AN-M57 and AN-57A1—striking velocity and angle of fall, and trail vs. drop charts.

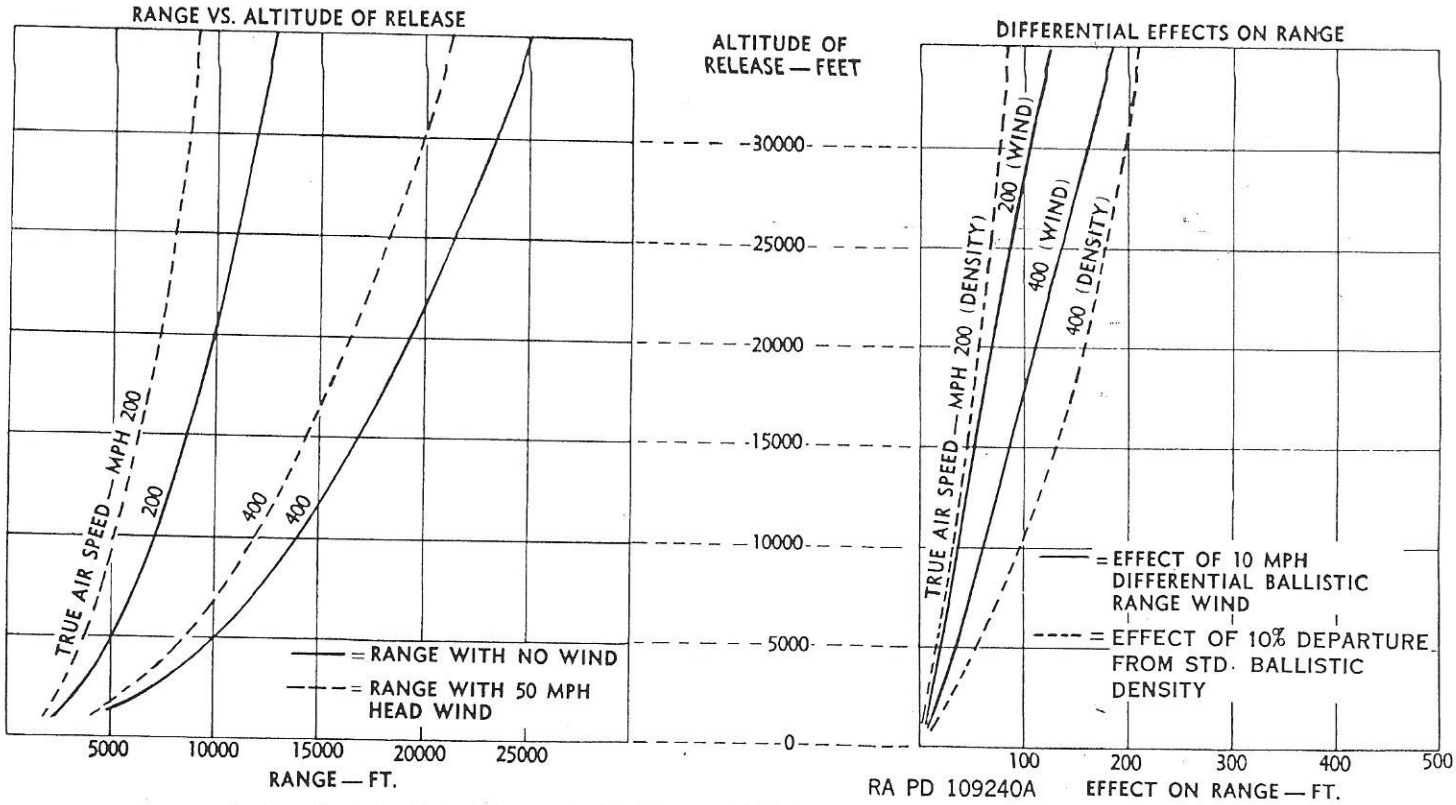


Figure 12. BOMB, GP, 500-lb, AN-M64 and AN-M64A1—range-altitude and differential charts.

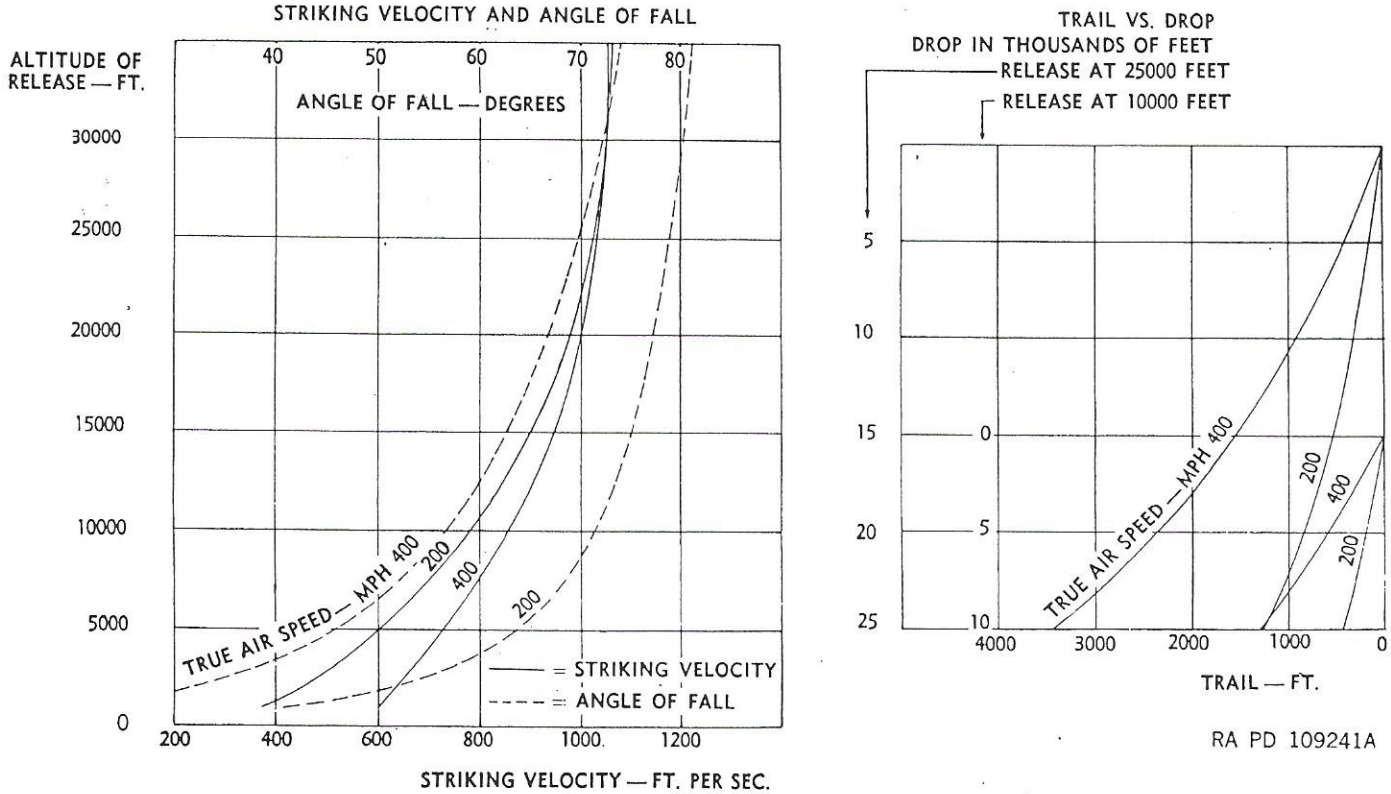


Figure 13. BOMB, GP, 500-lb, AN-M64 and AN-M64A1—striking velocity and angle of fall, and trail vs. drop charts.

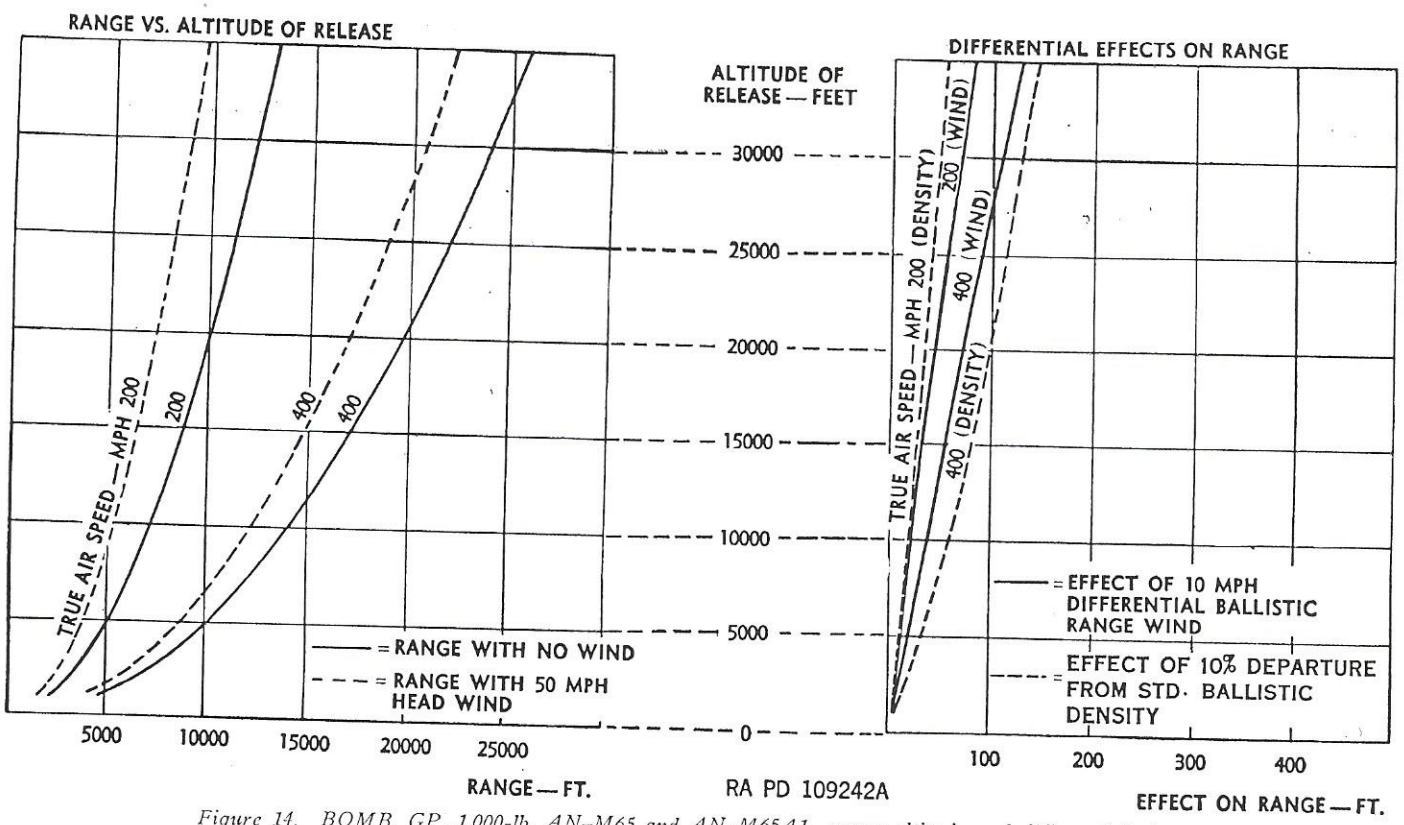


Figure 14. BOMB, GP, 1,000-lb, AN-M65 and AN-M65A1—range-altitude and differential charts.

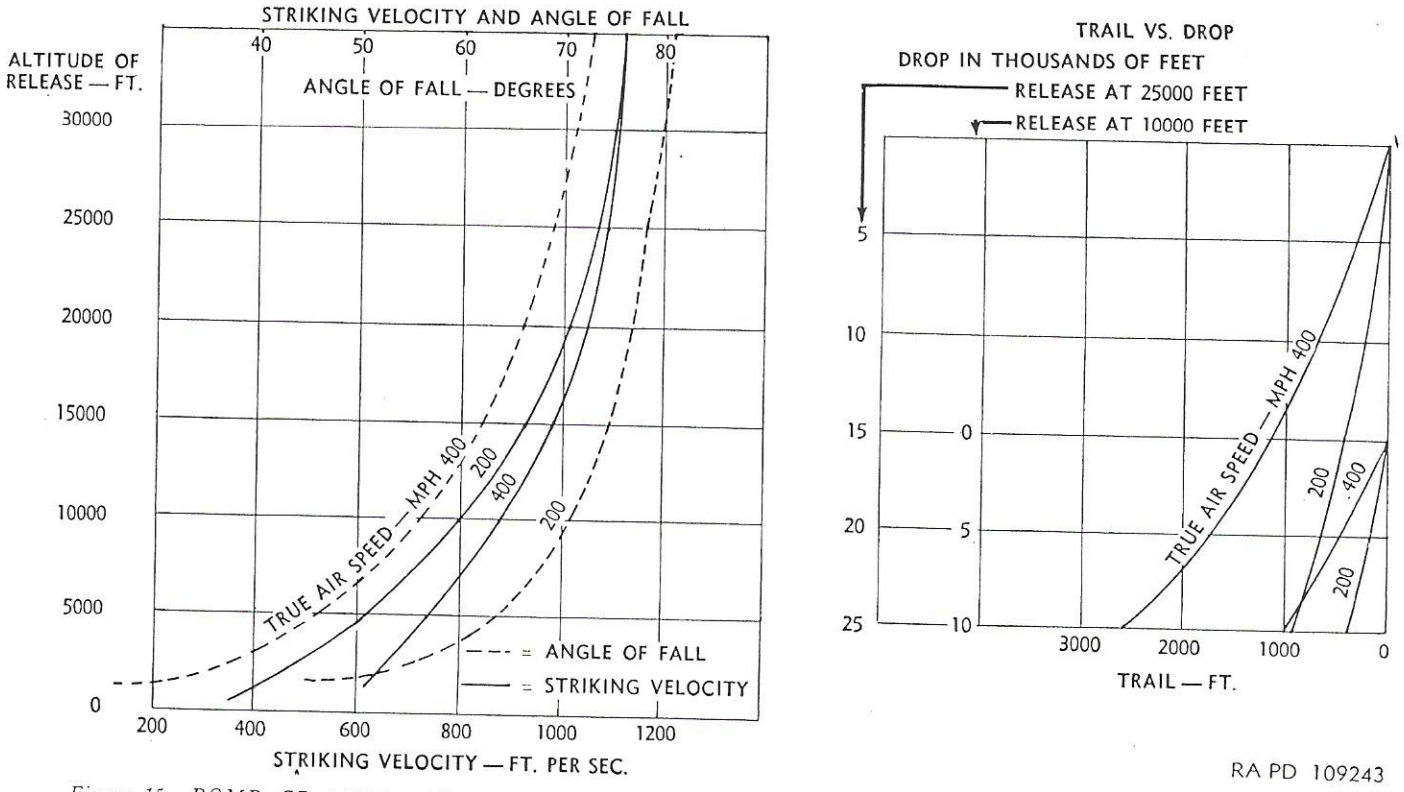


Figure 15. BOMB, GP, 1,000-lb, AN-M65 and AN-M65A1—striking velocity and angle of fall and trail vs. drop.

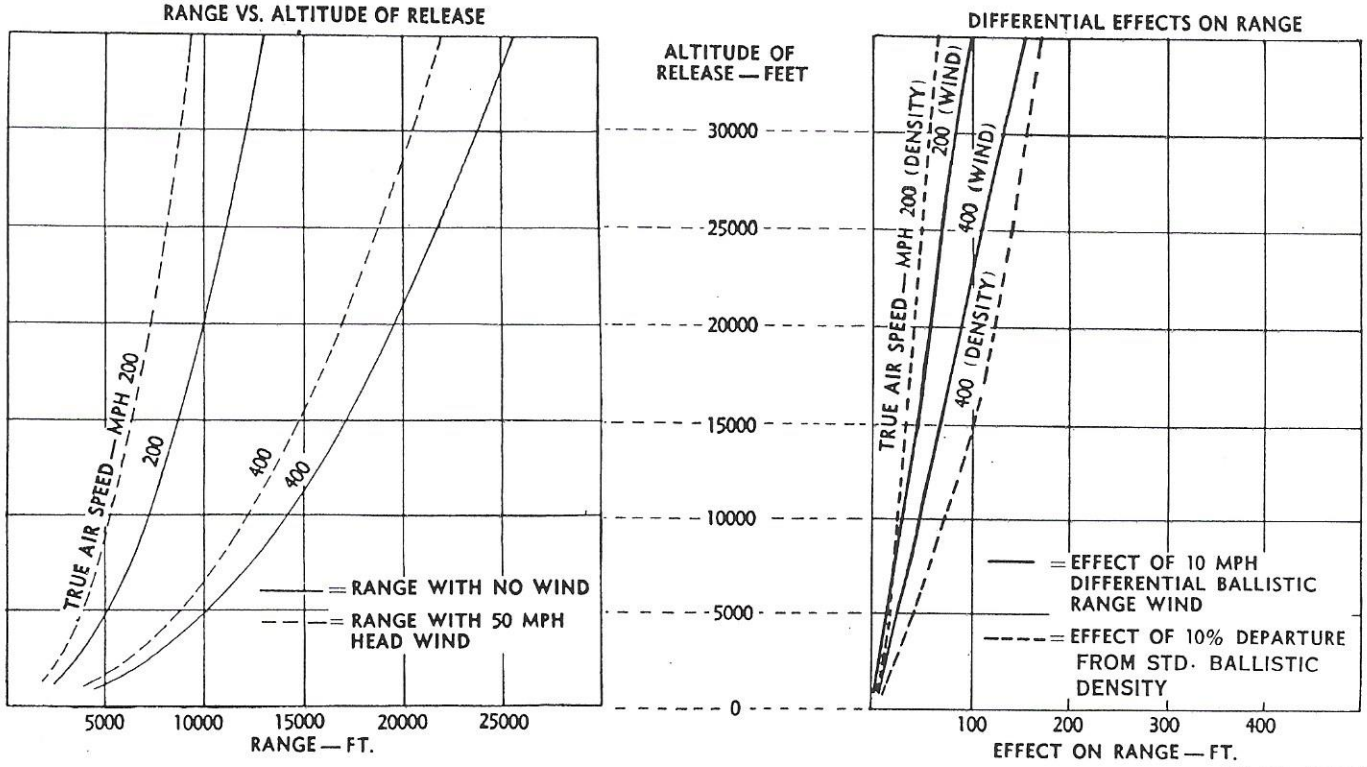


Figure 16. BOMB, GP, 2,000-lb, AN-M66, AN-M66A1, and AN-M66A2—range-altitude and differential charts.

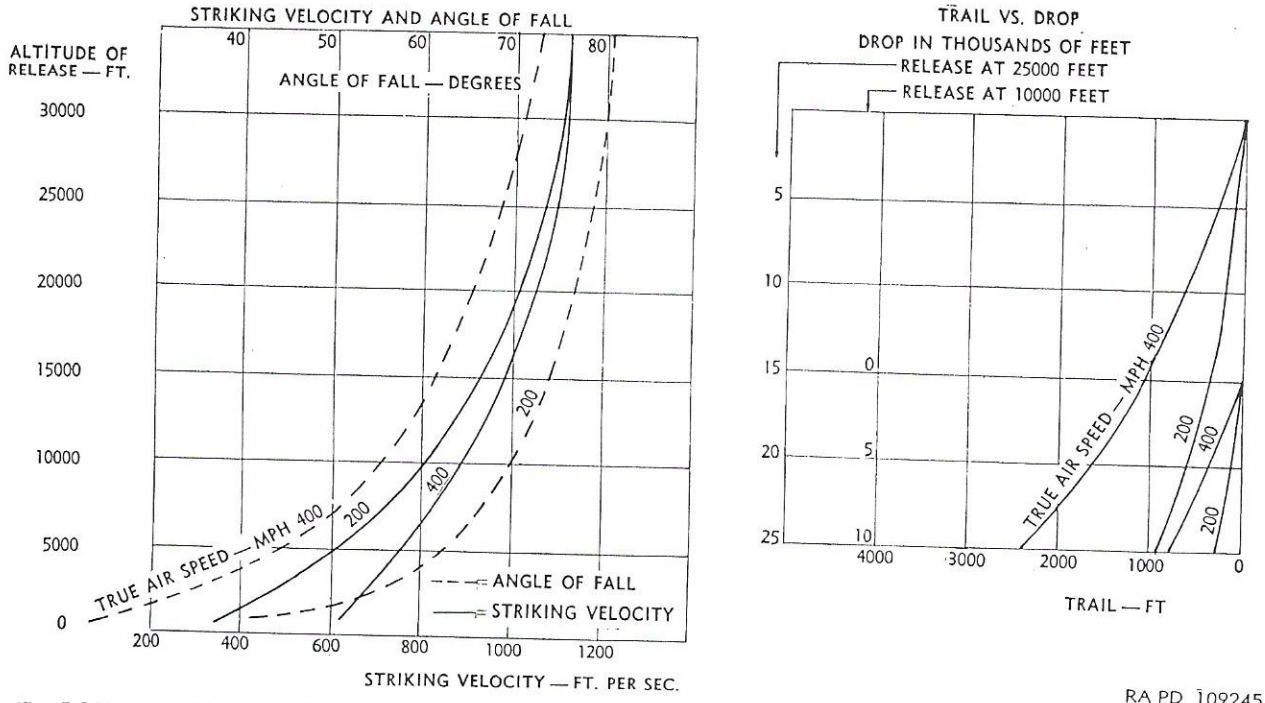


Figure 17. BOMB, GP, 2,000-lb, AN-M66, AN-M66A1, and AN-M66A2—striking velocity and angle of fall, and trail vs. drop charts.

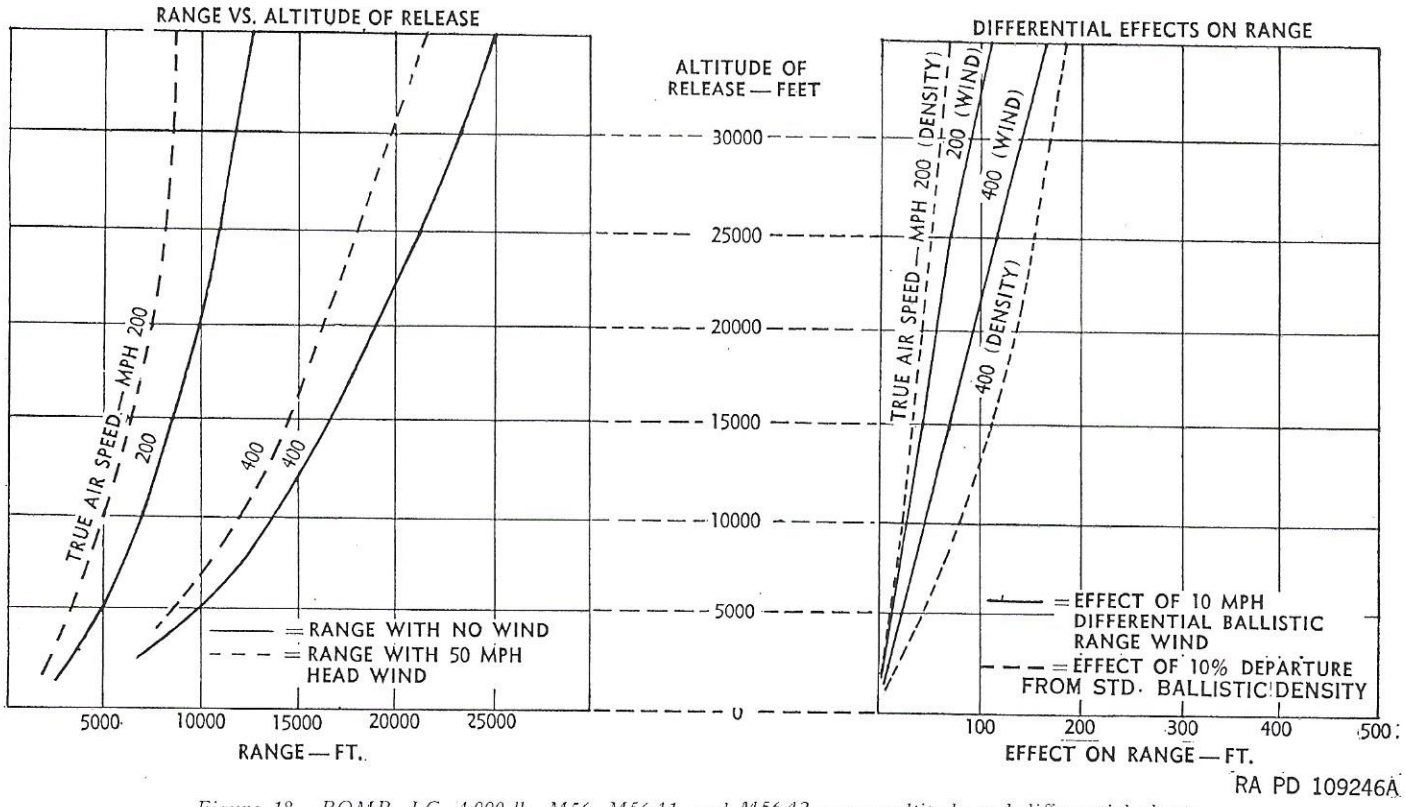


Figure 18. BOMB, LC, 4,000-lb, M56, M56A1, and M56A2—range-altitude and differential charts.

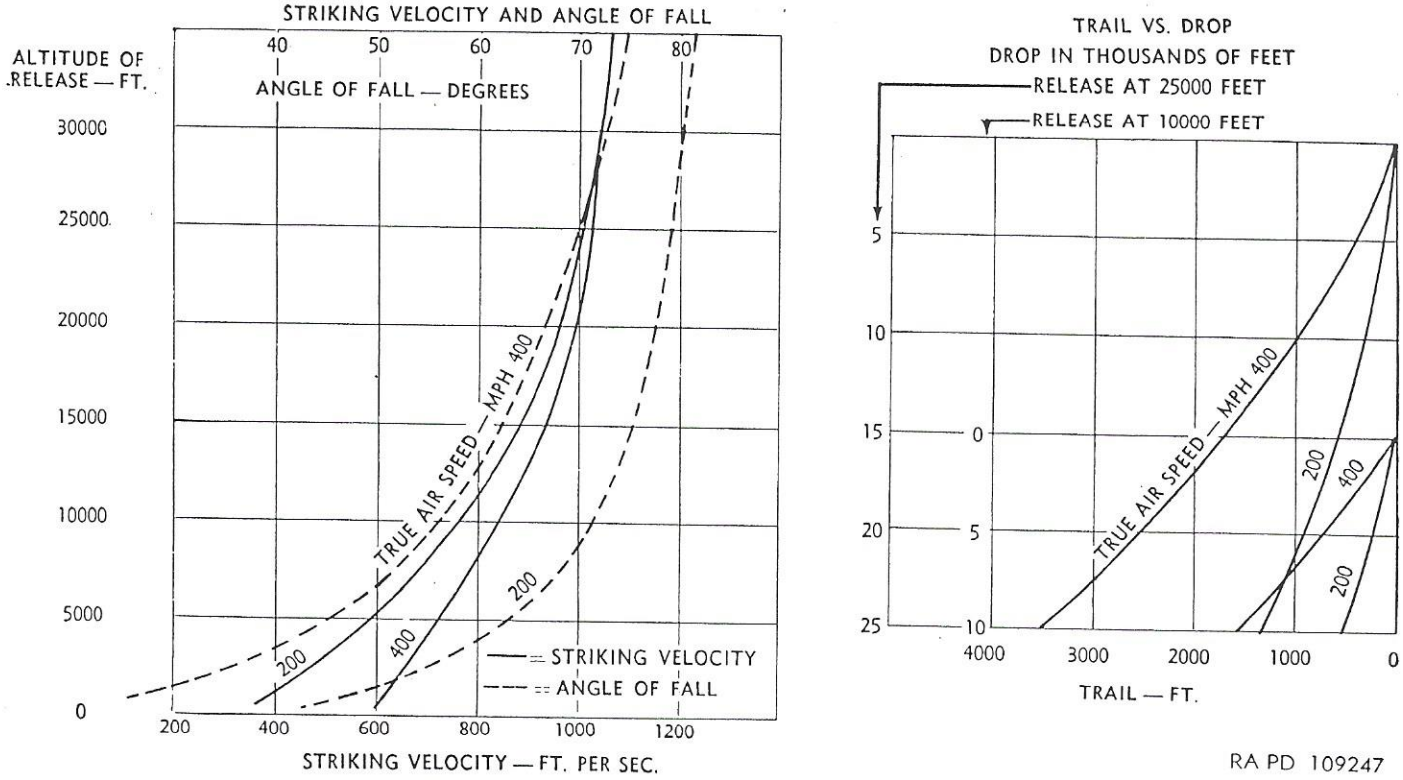


Figure 19. BOMB, LC, 4,000-lb, M56, M56A1, and M56A2—striking velocity and angle of fall and trail-drop charts.

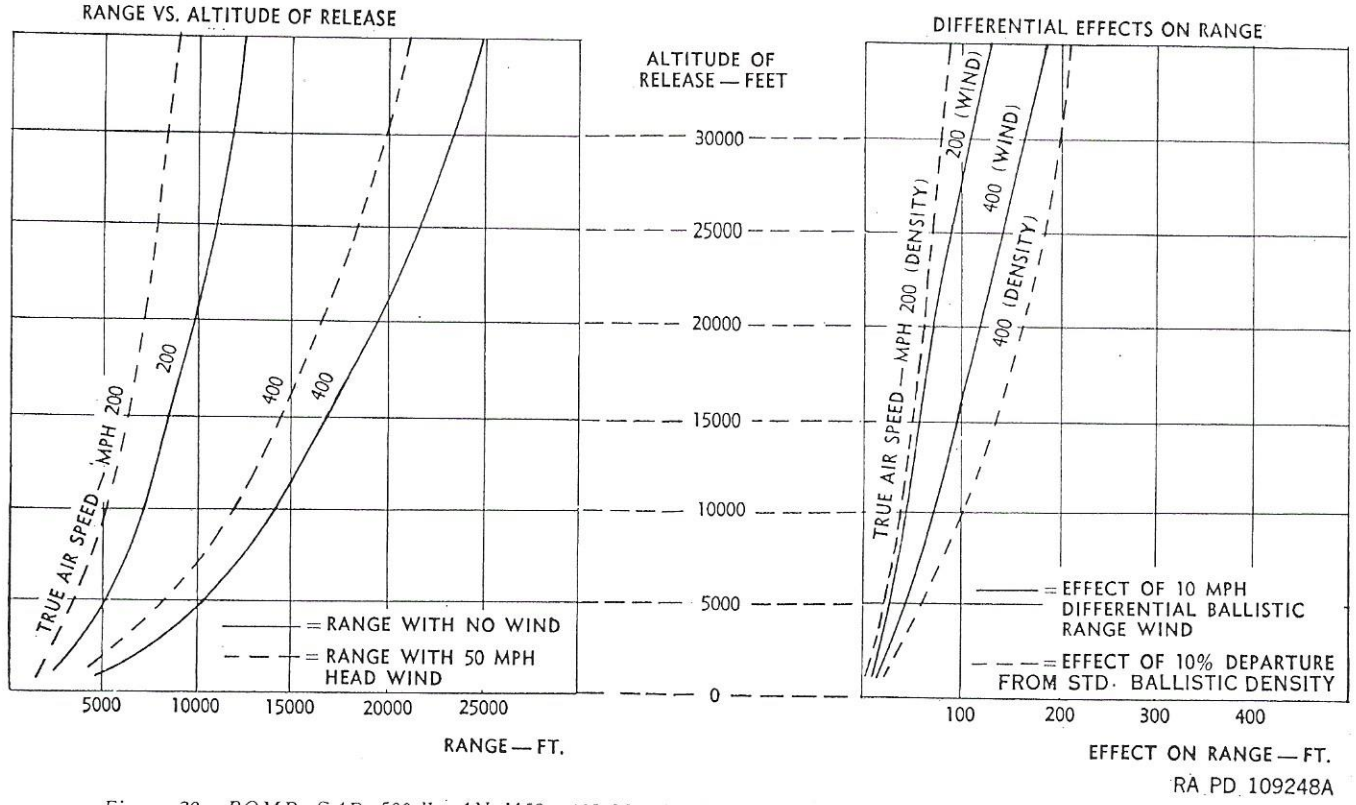


Figure 20. BOMB, SAP, 500-lb, AN–M58, AN–M58A1, and AN–M58A2—range-altitude and differential charts.

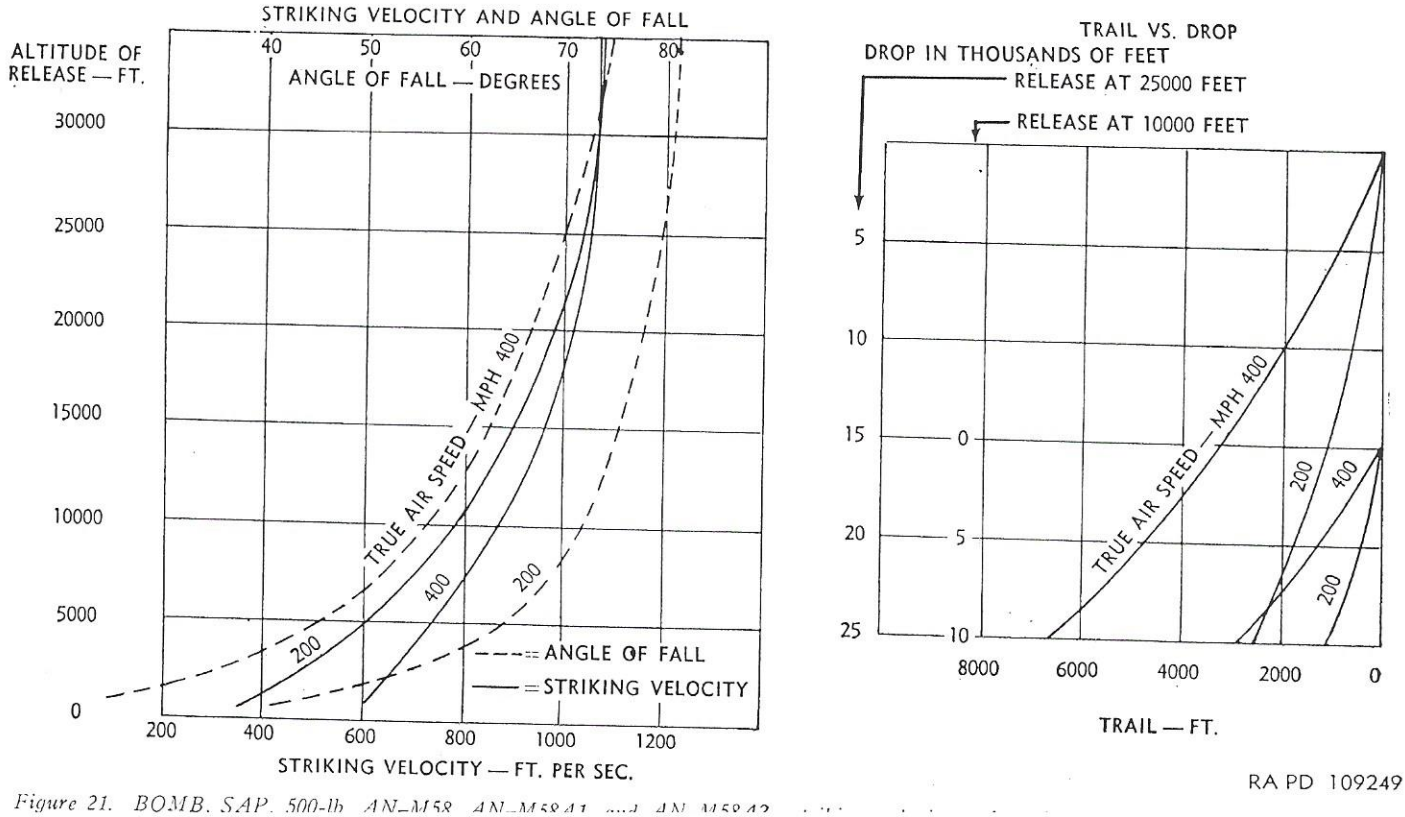


Figure 21. BOMB, SAP, 500-lb, AN–M58, AN–M58A1, and AN–M58A2—[illegible]

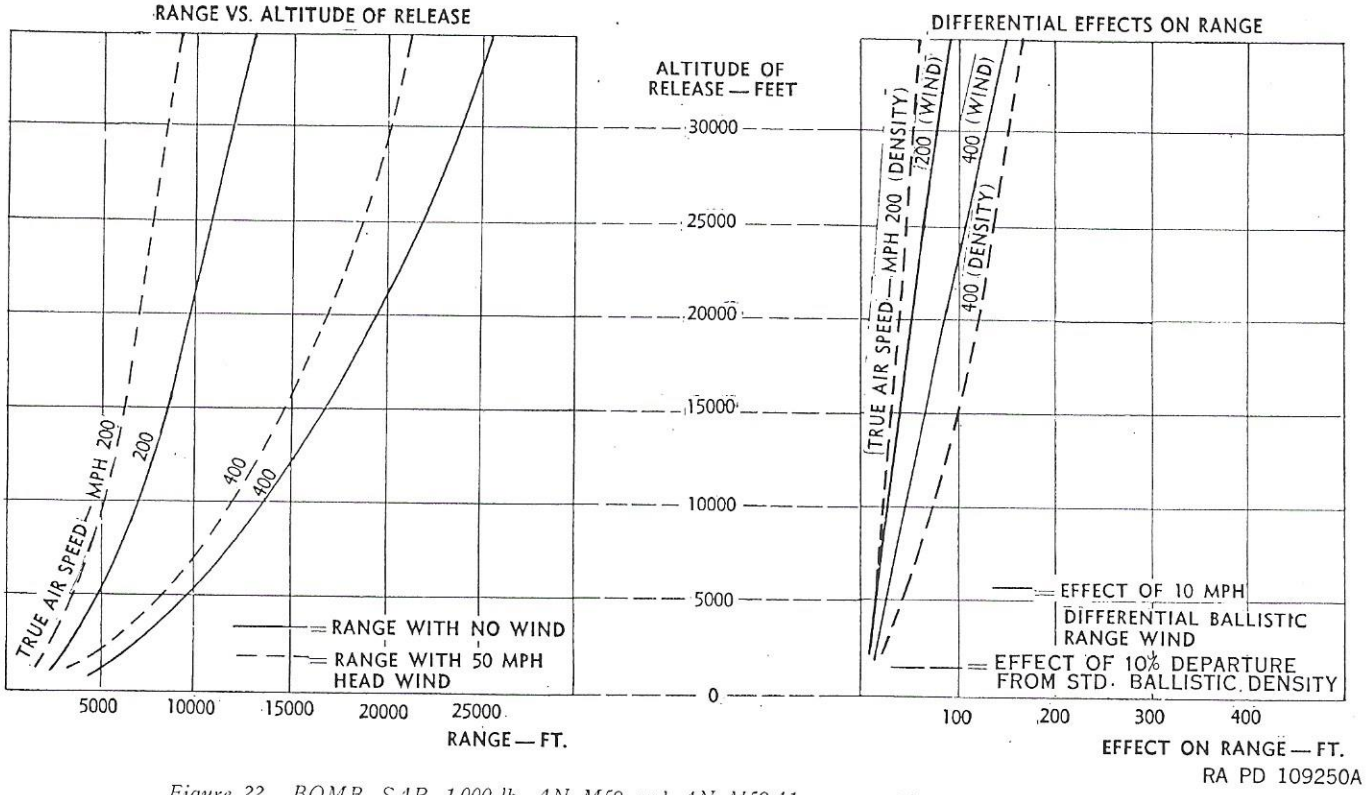


Figure 22. BOMB, SAP, 1,000-lb, AN-M59 and AN-M59A1—range-altitude and differential charts.

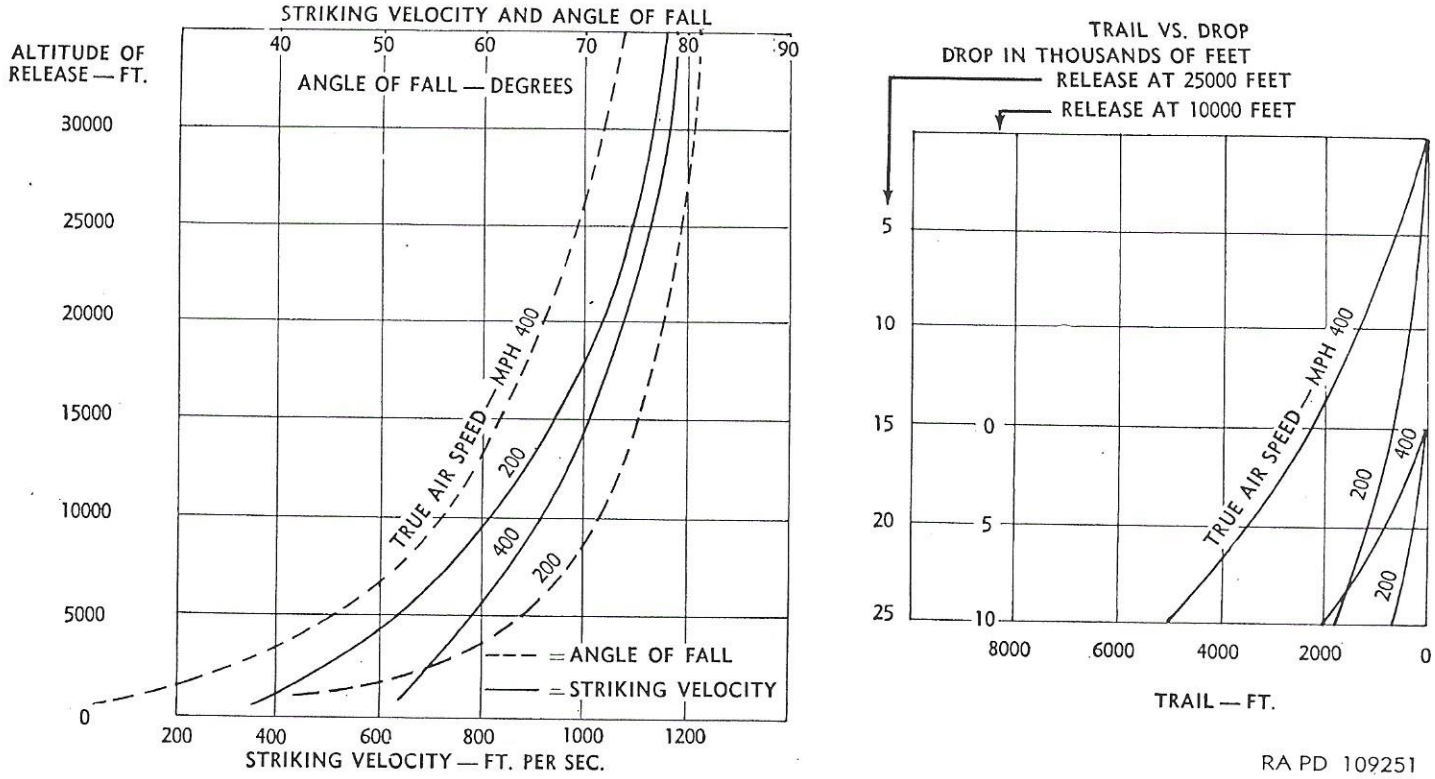


Figure 23. BOMB, SAP, 1,000-lb, AN-M59 and AN-M59A1—striking velocity and angle of fall, and trail vs. drop charts.

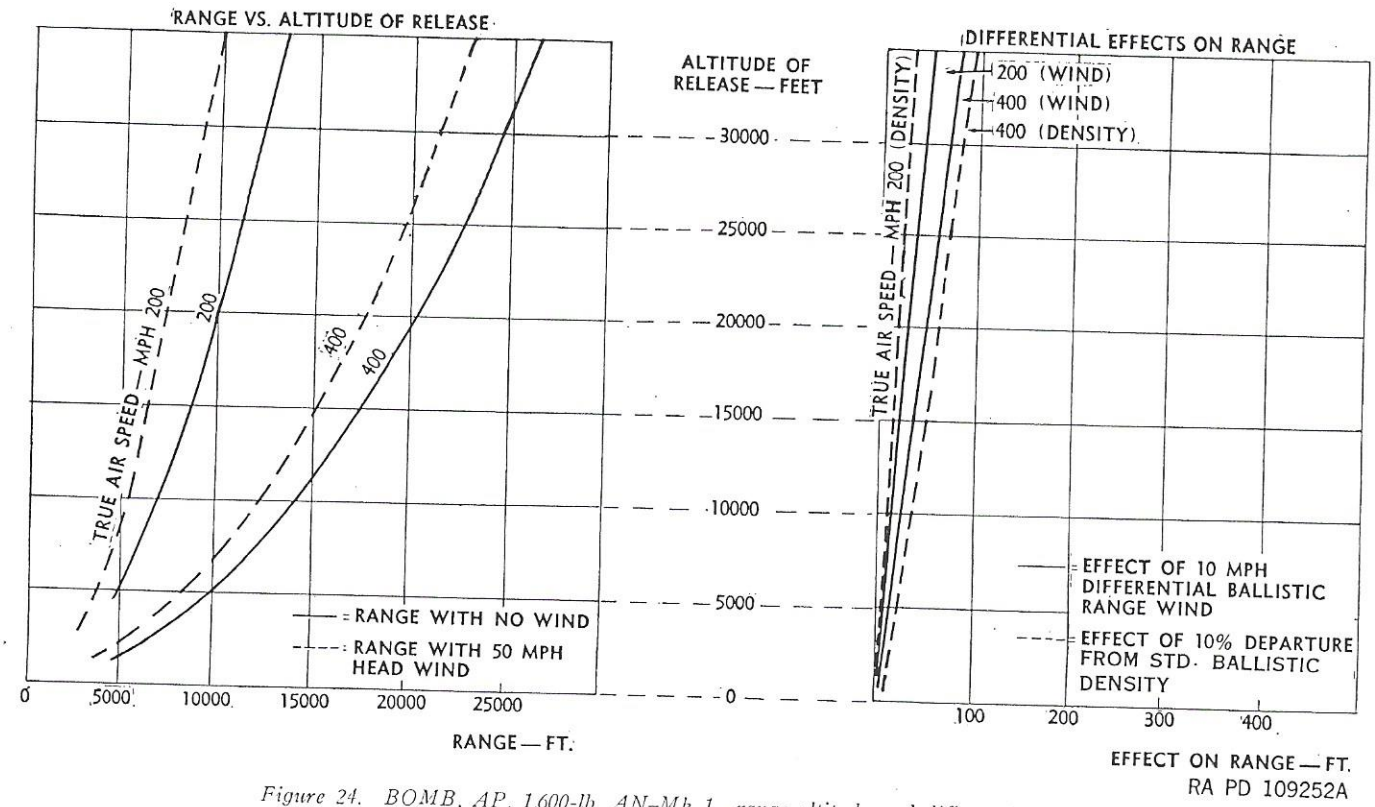
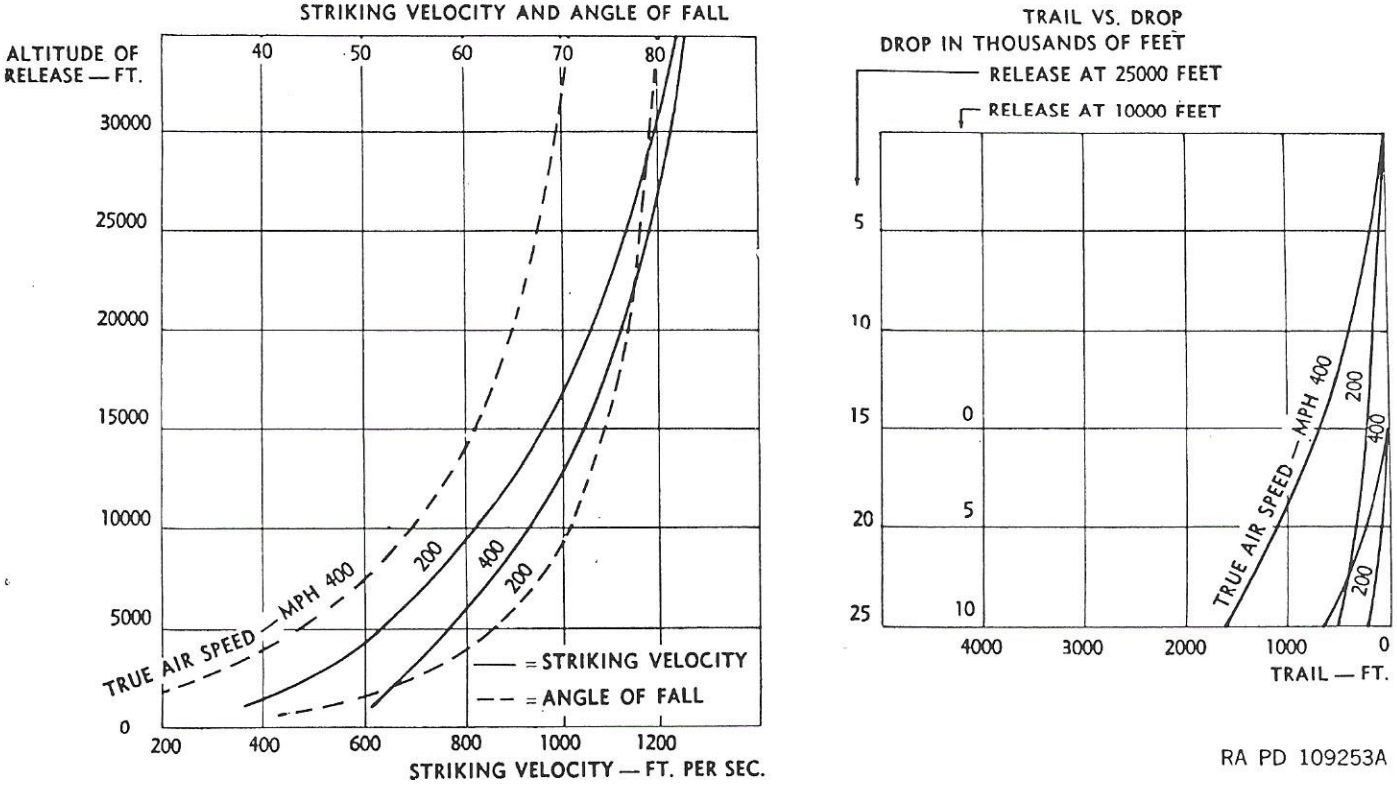


Figure 24. BOMB, AP, 1,600-lb, AN-Mk 1—range-altitude and differential charts.



Section II. LOW ALTITUDE BOMBING TRAJECTORIES

9. Trajectory Chart

a. Accuracy. The chart in figure 27 for solving low altitude trajectories of bombs is based on vacuum trajectories and neglects air resistance. It is sufficiently accurate for low altitude release; it is more accurate for dive bombing than for level or climb bombings from the same altitude; and it is more accurate for heavy than for light bombs. For example, in level bombing at 300 miles per hour from 4,000 feet, the values obtained from the chart are in error as follows:

100-lb GP bomb		*1,600-lb AP bomb*
5° low	Angle of fall	2° low
17% high	Striking velocity	2% high
7% long	Range	1½% long
4% low	Time of flight	1% low

b. Arguments. The chart is entered with the plane speed, angle of dive and altitude of release. From these data it gives time of flight, angle of fall and striking velocity directly, and range by the performance of a simple mathematical operation (*e* below).

c. Description. Figure 27 consists of two parts; the left half deals with velocities and direction; the right, with altitude of release and time of flight. In the left hand section, the horizontal and vertical scales give the horizontal and vertical components of velocity for the bomb and plane. The radial lines indicate, by their direction, the angle of dive of the plane or angle of fall of the bomb, and, by their length (using the curves as the scale), the actual velocity of bomb and plane. In the right hand section of the chart, altitude of release is plotted against vertical component of velocity giving curves of fall which are scaled in seconds to give time of flight.

d. Principle. The principle of figure 27 is as follows: The speed and dive angle of the plane at release are, necessarily, the initial velocity and angle of fall of the bomb. This vector is analyzed to obtain the horizontal and vertical components of initial bomb velocity. The horizontal component has the same value throughout the trajectory since air drag is neglected. The vertical component of initial velocity is applied to altitude of release to obtain the vertical component of final velocity and time of flight. The horizontal component is combined with the final vertical component to obtain striking velocity and angle of impact and is multiplied by time of flight to obtain range.

e. Use of Chart. The various steps in using the trajectory chart in figure 27 are illustrated in figure 26.

(1) Enter the chart with plane speed and follow the curve until it intersects the radius representing the given angle of dive. This intersection is the initial point. From this point, the horizontal and vertica components of initial velocity are read on the horizontal and vertica scales, respectively.

(2) Proceed right, along the line representing vertical componer of initial velocity, to the edge of the right hand section, and follow th curve of fall which starts at that point. Since curve of fall is plotte only at 50 ft/sec intervals, interpolation may be necessary. Follow th curve of fall till it intersects the line indicating the altitude of release This is the second point. From this point, the time of flight is read o the slanting time of flight lines, and vertical component of final velocit is read in the extreme left hand margin.

(3) Proceed left, along the line representing vertical component o final velocity, to a point directly below the initial point. This is th final point. The angle of the radius to this point gives the angle o fall (angle of impact), and the length of the radius read on the curve gives the striking velocity.

(4) Range is obtained by multiplying horizontal component of veloc ity by time of flight.

10. Dive Bombing

In solving dive bombing trajectories, the chart in figure 27 is usec as described above. For example: A bomb is released from 4,000 feet altitude from a plane diving at 60 degrees and 350 miles per hour. Enter the chart at 350 mph (513 ft/sec) and follow the curve to the radius for 60 degrees. The horizontal component of velocity is 255 ft/sec and the vertical component is 445 ft/sec. Follow the 445 ft/sec line to the right and follow the curve of fall down to 4,000 feet altitude line. The time of flight is 7.1 seconds and the final vertical velocity is 675 ft/sec. Follow the 675 ft/sec line left, to the 255 ft/sec line for horizontal component, that is, immediately below the initial point. The angle of fall is 69 degrees and striking velocity is 720 ft/sec. The range is 255 ft/sec multiplied by 7.1 seconds or 1,810 feet.

11. Level Bombing

In solving level bombing trajectories, the chart in figure 27 is used as described in paragraph 9, bearing in mind that in level bombing, the angle of dive is zero and horizontal velocity and plane speed at release are equal. For example: A bomb is released in level flight from 2,000 feet at 300 miles per hour. Enter the chart at 300 mph (440 f/s). This gives horizontal component of velocity immediately. Follow the top line to the right hand section then follow the top curve of fall to the 2,000-foot altitude line. The time of flight is 11.2 seconds and the final vertical velocity 358 ft/sec. Follow the 358 ft/sec line to the left

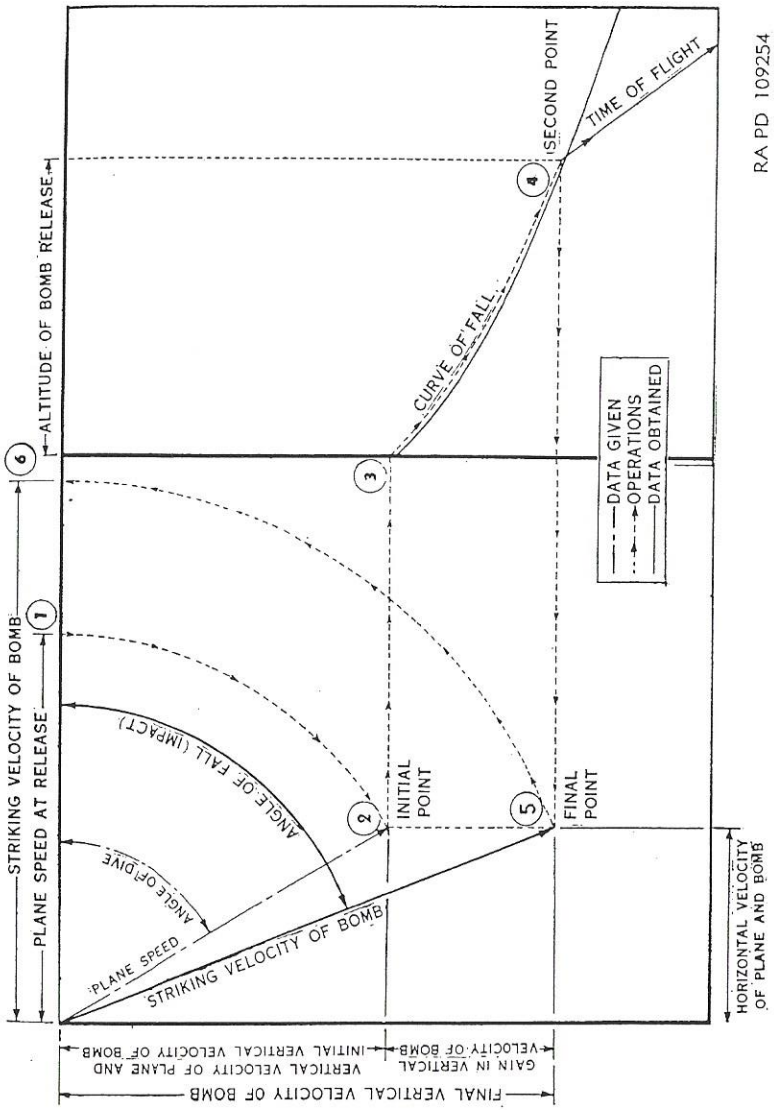
to the line representing 440 ft/sec horizontal velocity. The angle of fall is found to be 38 degrees and the striking velocity 565 ft/sec. The range is 440 ft/sec multiplied by 11.2 seconds, or 4,928 feet.

12. Climb Bombing

a. Principle. The trajectory of a bomb released from a climb may be considered to consist of three parts: first, a climb to the apex; second, descent from the apex to the altitude of release; third, fall from the altitude of release. In the first part, the vertical velocity of the bomb is negative, that is, the bomb *falls upward*. In the second part, the vertical velocity is increasing under the influence of gravity and, when the bomb has again reached the altitude of release, the vertical velocity has reached the same value it had at release but in the positive—*downward-direction*. At this point the angle of fall is the same as the angle of climb at release, and the time of flight from the apex is the same as the time required to rise to the apex from the altitude of release. The third part of the trajectory is treated as the ordinary case of dive bombing. In using the chart for solving climb bombing trajectories, the third part of the curve is solved directly as for dive bombing; the second part is solved for time of flight and this is doubled—to include the first part—and added to time of flight for the third part to obtain total time of flight and range.

b. Use of Chart. Enter the chart in figure 27 with plane speed and follow curve to radius indicating angle of climb. Horizontal and vertical components of velocity are read in the horizontal and vertical scales. Follow the line of vertical component: (1) to curve of fall for level bombing (top curve in right-hand section), and on this curve read time of flight for the second part of the trajectory; (2) to left edge of right-hand section and follow curve of fall to the altitude of release. From this point read time of flight for parts of trajectory and final vertical velocity. Follow line of vertical velocity left to horizontal velocity — directly below initial point — and read angle of fall and striking velocity. Double the time of flight for part 2, add to time for part 3, and multiply the sum by the horizontal component of velocity to obtain the range.

c. Example. A bomb is released at 3,000 feet altitude from a plane climbing at 20 degrees and 310 miles per hour. Enter the chart at 310 mph (455 ft/sec) and follow the curve to the 20 degree radius. The horizontal component of velocity is 428 ft/sec and the initial vertical component is 156 ft/sec. Follow the 156 ft/sec line to its intersection with the top curve of fall. The time of flight for second part of trajectory is 4.9 seconds. Follow the curve of fall starting at the 156 ft/sec line and follow it to 3,000 ft altitude. Time of flight for third part of trajectory is 10 seconds and final vertical velocity is 463 ft/sec. Follow



RA PD 109254

Figure 26. Use of trajectory chart (see fig. 27).

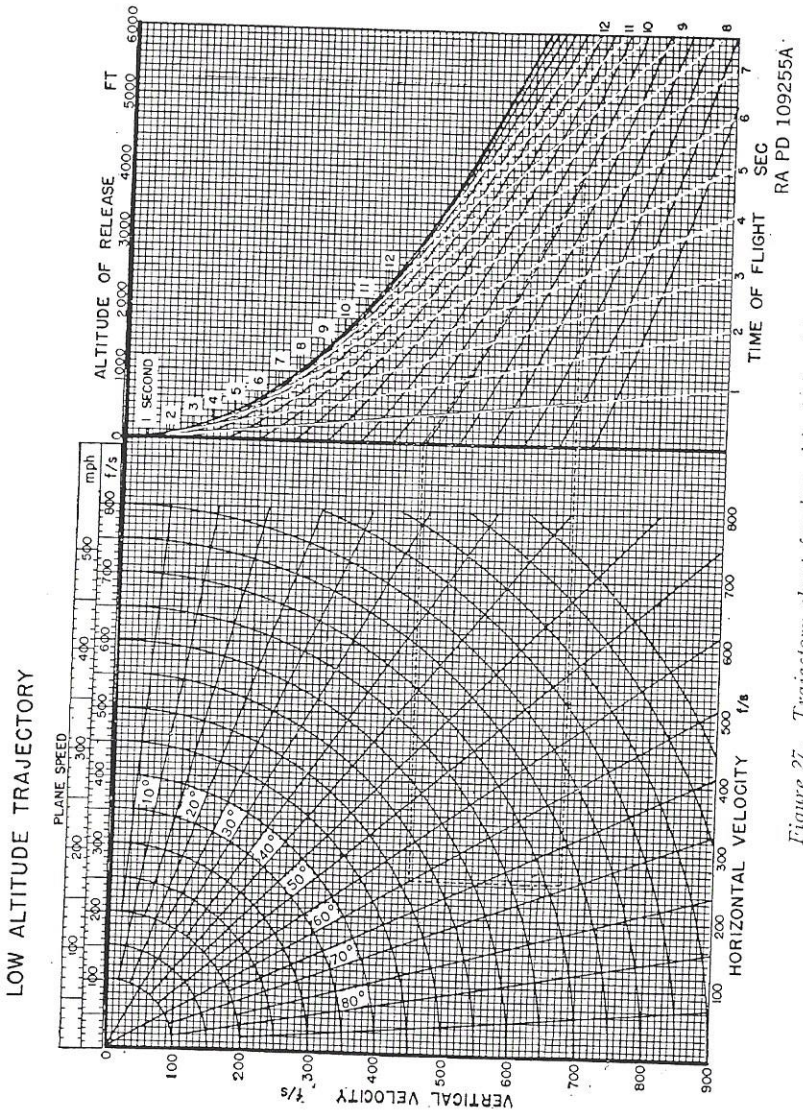


Figure 27. Trajectory chart for low-altitude bombing.

the 463 ft/sec line left to horizontal component line — 428 ft/sec for the final point. The angle of fall is 47 degrees and the strik velocity is 631 ft/sec. Range is computed as follows: Time of flig part 2, 4.9 seconds; double to include part 1, 9.8 seconds; add 10 s onds time of flight for part 3, 19.8 seconds; multiply by horizon velocity, 428 ft/sec, to obtain total range, 8,474 feet.

Section III. BOMB FUZE FUNCTIONING ON THIN ROO

13. General

a. The nose fuze in bombs presumably will be initiated by all roo but the tail fuze is inertia activated and will not function on t thinnest roofs. The effectiveness of the roof depends only on t weight per square foot. Table II gives, for various bombs and altitud of release, the lightest roof which will cause functioning of most of t bombs dropped when using the AN–M100, AN–M101, or AN–M1 series fuzes. Values are given for general-purpose and semiarmor-pierci bombs. For the latter category (SAP), the use of such a table will be determine whether the fuze will be initiated on the roof or the cella when bombs strike protected cellars that are covered by thin-roof buildings.

b. Roofs which are thinner than those tabulated may still initiate t fuze of a considerable fraction of the bombs. Only roofs one-third less of the thickness tabulated will pass most of the bombs witho initiation of the fuze. Roofs and floor thicknesses are not to be adde in estimating fuze action. That is, if the bomb must pass many laye of floors (spaced more than five feet apart) and no single one of t layers would initiate the fuze, then the multiple layers will, in genera not initiate the fuze.

Table II. Thickness of Roof Necessary to Cause Functioning of Tail Fuzes

Altitude of release Feet	Bombs: Size and type	Roofing			
		Weight lb/sq ft	Concrete thickness, in.	Steel sheet thickness, in.	Sheet metal US std gag
5,000	100-, 250-lb GP	3	¼	1/12	14
	500-, 1,000-lb GP	4.5	⅜	⅛	11
	2,000-lb GP; 500-, 1,000-lb SAP	6	½	⅙	9
10,000	100-, 250-lb GP	2.5	¼	1/15	16
	500-, 1,000-lb GP	3.5	⅓	1/10	13
	2,000-lb GP; 500-, 1,000-lb SAP	4.5	⅜	⅛	11
20,000	100-, 250-lb GP	2	⅙	1/20	18
	500-, 1,000-lb GP	3	¼	1/12	14
	2,000-lb GP; 500-, 1,000-lb SAP	4	⅓	1/10	12

14. Shock Front

a. GENERATION. The hot gases ejected by a detonating bomb sweep out and compress the surrounding air and throw that compressed body of air against adjacent layers of air. In this way a belt is formed within which the air has high pressure and high outward velocity. This belt is limited by an extremely sharp front (less than one thousandth of an inch) called the "shock front" in which the pressure rises abruptly.

b. TRAVEL. The shock front travels away from the point of detonation with an extremely high initial velocity; for example, it is 3,000 feet per second at 60 feet from a 4,000 pound light-case bomb where the pressure jump is 100 pounds per square inch. As the shock front travels on, its velocity then decreases rapidly towards the velocity of sound, about 1,100 feet per second, and the pressure jump decreases.

c. DURATION. The excess pressure prevailing at a point in the air after the arrival of the shock front decreases and vanishes in a short time (about 0.04 second at 400 feet from a 4,000 pound light-case (LC) bomb; about 0.006 second at 50 feet from a 100-pound general-purpose (GP) bomb, and is followed by minor disturbances which often include a partial vacuum. The entire disturbance produced in air by detonation of a bomb is called "blast".

15. Peak Pressure

a. DEFINITION. The peak pressure is the highest excess pressure (that is, the pressure in excess of that directly in front of the shock front) which is attained right at the shock front. It gives a measure of the maximum force exerted against a structure by the blast (pressure times area = force). Figure 29 shows the peak blast pressure plotted against the distance from the point of burst for various bombs. The peak pressure required to produce certain specific effects also is shown. The numbers in figure 29 refer to the hydrostatic pressure, which is that measured on a surface which is "side on" to the blast, that is, parallel to the direction of travel.

b. EFFECT OF ORIENTATION. The orientation to the shock front of the surface on which blast pressure is measured has a great effect on the pressure recorded (fig. 28). The blast effect received by a surface which is parallel to the advancing shock front is greater by several times than that received by a surface which is edge-on to the exploding bomb. This ratio varies from eight at very short distances to two at very long distances from the point of detonation. The effect on oblique surfaces is intermediate.

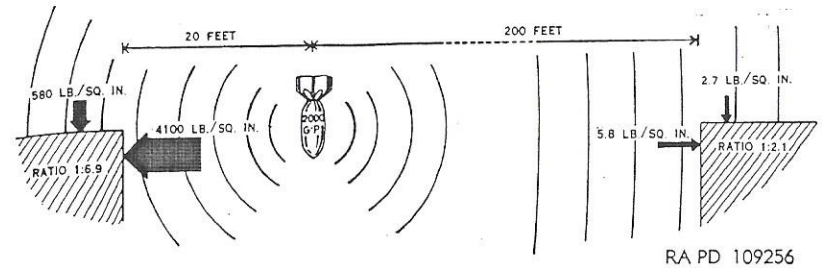


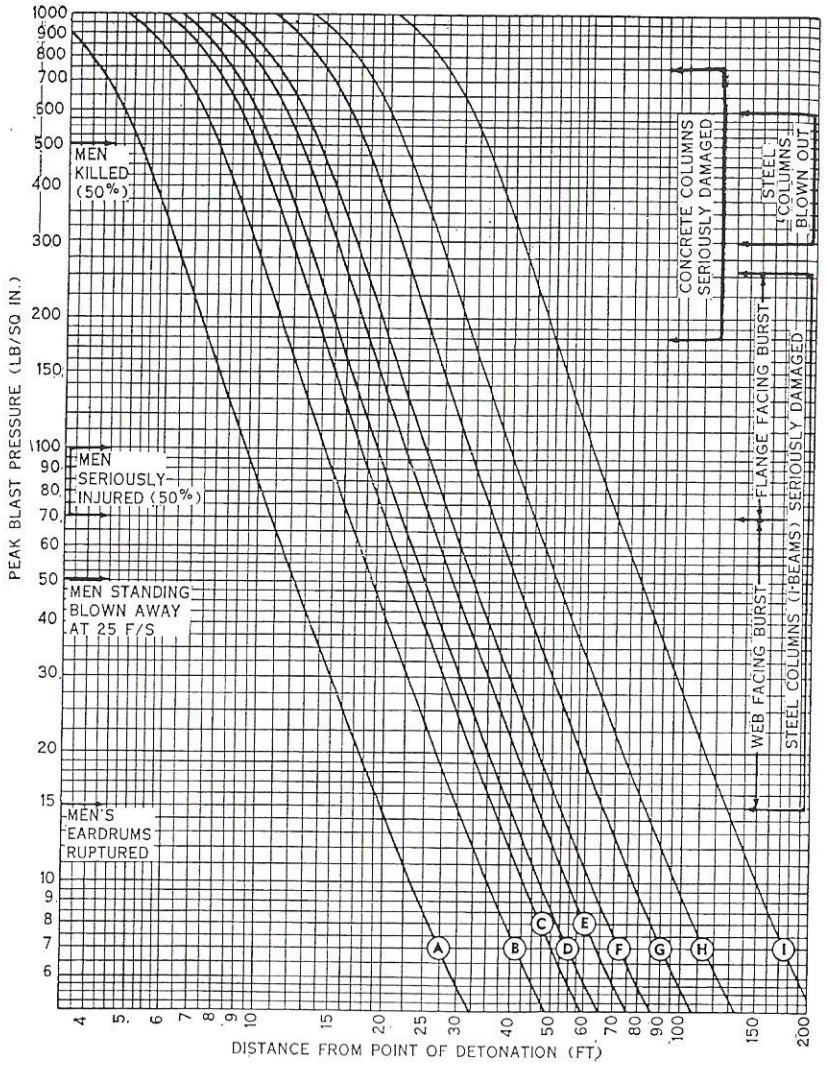
Figure 28. Effect of orientation on blast pressure.

16. Impulse

A blast cannot travel quickly around anything as large as the wall of a house; therefore the pressure difference established by the blast on the outer and inner faces of such a wall persists until the blast has subsided. As a result of the great inertia of walls, the deformation produced by the blast seldom attains the point of collapse before the blast has subsided; the wall keeps on deforming further after that time, again a result of its inertia, which now tends to overcome the structural strength. The eventual attainment of a deformation leading to collapse will depend on the velocity acquired by the wall under the impact of the blast. This velocity depends in turn not only on the blast pressure but also on its duration, specifically, on its measurable impulse which is the average pressure multiplied by the duration (that is, the integral of pressure with respect to time).

17. Radii and Areas of Effectiveness

The damage caused by various types of bombs in load bearing wall construction (see fig. 30) can be correlated with the blast impulse measured at various distances from the bomb. Therefore, the known relation of impulse to distance for any type of bomb can be used to estimate the distance at which the bomb would cause a certain degree of damage. Radii and areas of blast effectiveness for bombs have been obtained in this way and are shown in figures 31 and 32 and table III. Data for bombs and fuzes which do not correspond to a normal tactical employment are included in table III, because these data also serve to indicate the comparative blast effectiveness of different bombs on targets other than load bearing wall construction. Table III purports only to represent the results of mathematical extrapolation of rules that have been established for medium and large bombs. It is intended mainly as a guide to the relative effectiveness of different bombs. Data for the effectiveness of bombs on buildings of light construction are not yet available. However, it has been estimated that the areas of effectiveness may be at least five times greater than the corresponding areas for load bearing construction.



A—BOMB, FRAGMENTATION. 260-LB. AN-M81

B—{BOMB. GP. TNT. 100-LB. AN-M30. AN-M30A1
BOMB. AP. 1000-LB. AN-MK 33

C—BOMB. SAP. TNT. 500-LB. AN-M58. AN-M58A1. AN-M58A2

D—{BOMB. GP. TNT. 250-LB. AN-M57. AN-M57A1
BOMB. AP. 1600-LB. AN-MK 1

E—BOMB. SAP. 1000-LB. AN-M59. AN-M59A1

F—BOMB. GP. TNT. 500-LB. AN-M64. AN-M64A1

G—BOMB. GP. TNT. 1000-LB. AN-M65. AN-M65A1

H—BOMB. GP. TNT. 2000-LB. AN-M66. AN-M66A1. AN-M66A2

I—BOMB. LIGHT CASE. TNT. 4000-LB. M56. M56A1. M56A2 RA PD 109257A

Figure 29. Peak blast pressure vs distance from bomb burst.

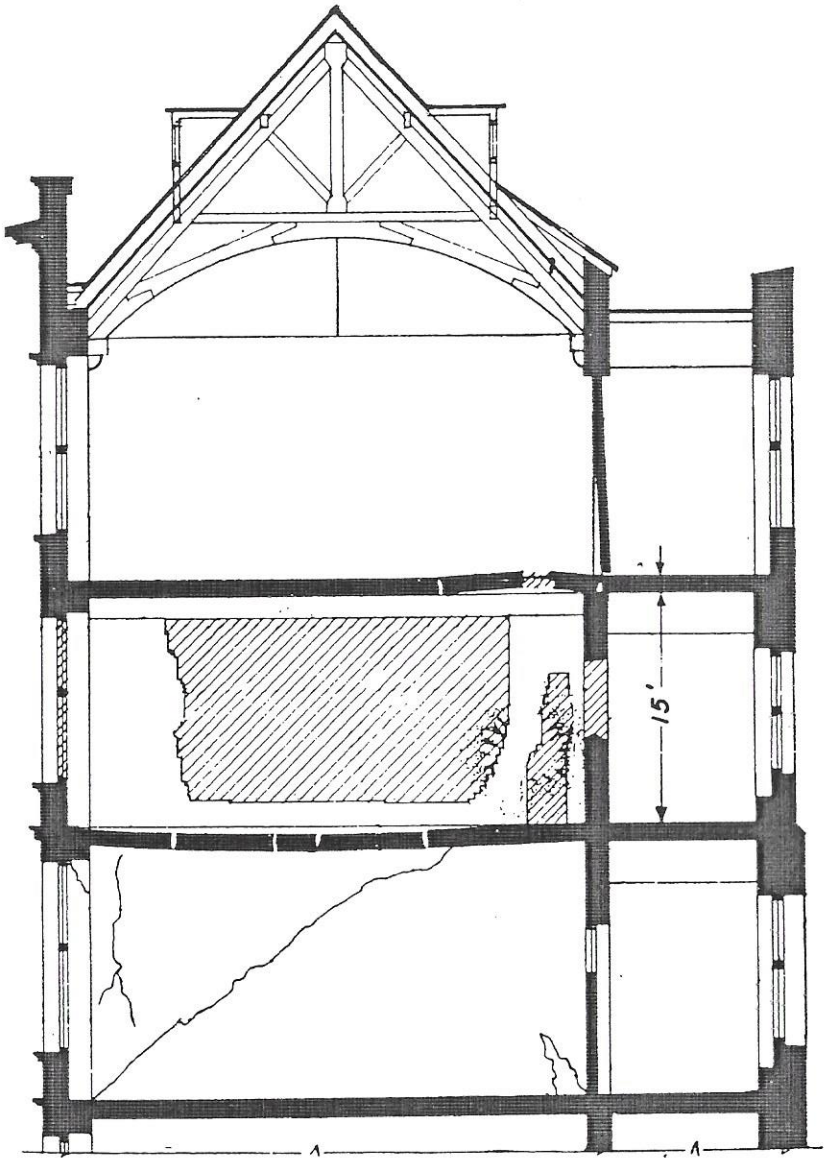


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Figure 30. Load-bearing wall construction.

18. Effects of Confinement

The presence of obstacles that prevent the effect of blast in some direction may increase the effect of blast in other directions. A blast wave traveling along a tunnel, a corridor, a trench, and in the case of large bombs, even along a street, is effectively confined, so that its intensity decreases much more slowly than in the open. When a bomb detonates inside a house, demolition of the walls may occur even if the distance to the walls exceeds the radius of demolition for the same wall and for the same type of bomb bursting in the open. This is due to a variety of effects, among which is the "multiple punch" effect created by the blast waves striking a wall in quick succession after having been reflected by other walls. For this reason, separate radii and areas of demolition are given in table III for bombs bursting inside and outside of buildings. If the effect of a blast is intensified on one side of a wall by its confining action, it is reduced by the same token on the opposite side of the wall by its screening action (see fig. 31).

19. Protection from Blast

A wall effectively reduces blast pressure and impulse on objects close behind it, if it is about 10 feet by 10 feet or larger and is of sufficient strength to withstand the blast. Foxholes, slit trenches, or ditches reduce the blast pressure by about 50 percent in the range where serious injury to personnel would otherwise occur. A single right-angle bend in a tunnel reduces the blast pressure about 50 percent. A system of four such bends reduces it to about 15 percent.

20. Effect of the Type of Explosive

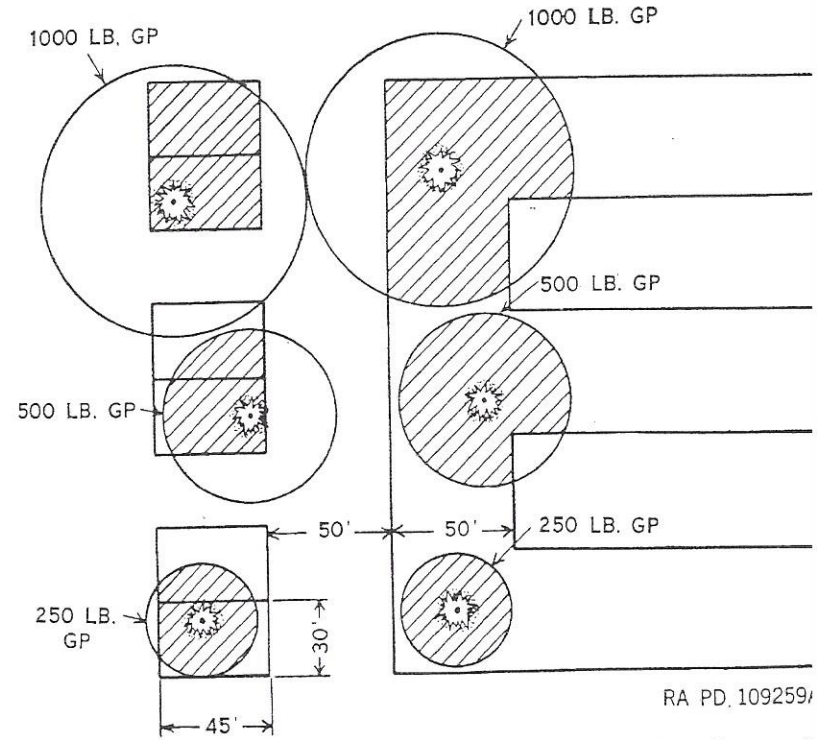
The data in figures 29, 31, and 32, and table III, refer to TNT fillings. Relative blast effectiveness of other explosives is given in table IV.

21. Effect of Charge Weight Ratio

The action of the explosive of a bomb detonating in air imparts a great speed to the bomb casing. The casing breaks up into fragments. Later the action produces an air blast. The lighter the casing, the less energy it takes to accelerate it. Therefore, a high charge/weight ratio increases the effect of detonation in air in a twofold manner; (1) it will reduce the fraction of energy taken up by fragments, and (2) it will increase the weight of charge included in a bomb of given weight. Hence, LC bombs are best among present bombs from the standpoint of blast effectiveness.

22. Effect of Blast on Industrial Structures

The demolition of industrial structures, which generally are steel frame cannot be analyzed in the same comparatively simple terms as th demolition of buildings with load bearing walls. It has been estimate that the factory area whose structure is damaged effectively by a dire hit with the 500 pound GP bomb AN–M64 with a 0.01 second fu delay averages about 400-450 square yards (1,600-1,800 square yar per ton). A considerable reduction of damage is experienced if th same bomb is fuzed 0.025 second delay, because its detonation the occurs far below the roof structure. The area of factory structure dan aged by various other GP bombs is not very different, when expresse



Bombs detonating inside buildings, as given in figure 32, with load bearing wall constructi A series of duplex houses, each 30 x 45 feet, is shown at the left of a 50-foot street an 50-foot deep block is shown at the right. Shaded areas indicate extent of probable demoliti

Note that—

(1) Area of circles increases faster than the weight of the bombs.

(2) Where the radius of effectiveness exceeds the dimensions of the building, there i loss of efficiency. Consequently larger bombs are more efficient against larger buildi smaller bombs against smaller buildings.

(3) Demolition does not extend to buildings other than the one directly hit (upper le

(4) Near misses produce cratering and earth shock effect (sec. VI, ch. 2).

Figure 31. Demolition of buildings with load-bearing walls by direct hits of delay-fuzed GP bombs.

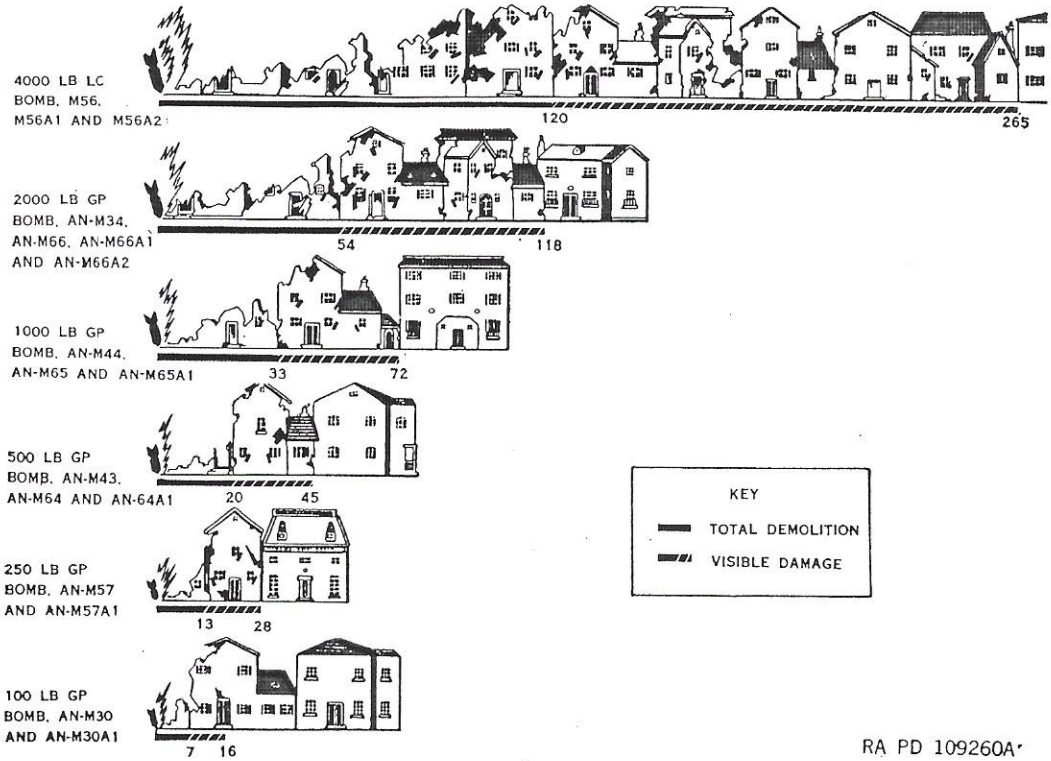


Figure 32. Area of effectiveness of blast.

Table III. Radii and Areas of Effectivencss of TNT Loaded Bombs

Bomb	Detonation outside building on ground or roof (bomb must be fuzed instantaneous)						Detonation inside building (direct penetration hit only) (bombs must be fuzed delay)	
	Demolition			Visible damage			Demolition	
	Mean radius (ft)	Maximum radius (ft)	Mean area (sq yd)	Mean radius (ft)	Maximum radius (ft)	Mean area (sq yd)	Mean radius (ft)	Mean area (sq yd)
4,000-lb LC, M56, M56A1 or M56A2	120	150	5,000	265	(330)	24,000	(200)††	(14,000)*††
2,000-lb GP, AN-M34, AN-M66, AN-M66A1 or AN-M66A2	54	66	1,000	118	(150)	4,900	(90)††	(2,900)*††
1,000-lb GP, AN-M44, AN-M65 or AN-M65A1	(33)	(40)	(375)	(72)	(90)	(1,800)	55	1,000*
500-lb GP, AN-M43, AN-M64 or AN-M64A1	(20)†	(25)†	(150)†	(45)	(56)	(700)	35	400*
250-lb GP, AN-M57 or AN-M57A1	(13)†	(15)†	(60)†	(28)	(35)	(275)	22	160
100-lb GP, AN-M30 or AN-M30A1	(7)†	(9)†	(17)†	(16)†	(20)†	(90)†	12	50
1,000-lb SAP, AN-M59 or AN-M59A1	(18)†	(22)†	(110)†	(39)	(48)	(500)	30	300
500-lb SAP, AN-M58, AN-M58A1 or AN-M58A2	(11)†	(13)†	(40)†	(24)	(30)	(200)	18	100
1,600-lb AP, AN-Mk 1	(12)†	(14)†	(50)†	(26)	(32)	(240)	(20)	(150)
1,000-lb AP, AN-Mk 33	(9)†	(11)†	(28)†	(20)†	(25)†	(140)†	(15)	(80)
260-lb Frag, AN-M81	(3)†	(4)†	(3)†	(7)†	(9)†	(17)†	(5)†	(9)†

See text for significance of these data.

Figures in parentheses do not correspond to normal or advisable tactical employment of the bomb in question, and are shown mainly for purpose of comparison.

Starred figures should be scaled down in keeping with limited size of buildings.

Figures marked with a † are believed to be lower than the actual damage due to the neglect of fragment damage and some other effects.

The figures marked †† are probably greater than the real damage due to the effect of building design and other neglected effects.

in square yards per ton of bombs. No direct evidence is available on the effectiveness of the U.S. 4,000 pound LC bomb on factory structures, but allied experience indicates that the damage by this type of bomb is greater than that of any other GP bomb, when expressed in square yards per ton of bomb load.

Table IV. Relative Blast Effectiveness of Various Explosives: TNT = 100

Explosive	Peak pressure (at equal distances)	Effectiveness against load-bearing wall construction	
		Radius	Area
Torpex (RDX/TNT/AL: 42/40/18)	122.5	125	156
HBX (RDX/TNT/AL/Wax: 40/38/17/5).	117.5	120	144
Minol (NH_4NO_3/TNT/AL: 40/40/20).	115	117.5	138
Tritonal (TNT/AL: 80/20)	112.5	117.5	138
DBX (NH_4NO_3/RDX/TNT/AL: 21/21/40/18).	112.5	112.5	127
RDX Comp B (RDX/TNT: 60/40)	110	110	121
Ednatol (Halite/TNT: 57/43)	105	105	111
TNT	100	100	100
Picratol (Expl. D/TNT: 52/48)	100	100	100
Amatex (NH_4NO_3/RDX/TNT: 43/9/48).	100	97.5	95
Amatol (NH_4NO_3/TNT: 50/50)	95	87.5	77

Section V. BOMB FRAGMENT DAMAGE

23. Choice of Bombs

a. Comparison Table. Table V will be useful in making a choice of bomb for ground burst against unshielded targets according to the type of fragment damage desired. In this table the groups of bombs compared are those normally carried in the same station. The types of damage are defined in paragraph 24. The figures given are ratios of effective hits of the type indicated for the bombs compared. The type of explosive charge in the bombs compared is as follows:

20-lb frag bomb (and 23-lb parafrag)	TNT.
90-lb frag bomb	Comp B.
100-lb GP bomb	Amatol.
260-lb frag bomb	Comp B.
500-lb GP bomb	Amatol.

b. General Considerations. At low or medium altitudes the pound fragmentation bomb, AN–M41 or AN–M41A1, is to be preferr against personnel or when only light damage is desired. For low al tude bombing, as noted in table V, the parachute on the 23-pound fra mentation bomb, M40 or M40A1 greatly improves its effect over t nonparachute bomb AN–M41 which, except for having fins instead a parachute, is identical with the M40 bomb. When released from hi altitudes, the 20-pound fragmentation bomb AN–M41 or AN–M41A is reduced in effectiveness. The bombs should be used in accordance wi the type of damage required, consulting tables V and VI and figures and 35. The 90-pound fragmentation bomb M82 may be used clusters of six and when so used will be particularly effective if t required damage is at most equivalent to perforation of ¼ inch mi steel. When this bomb is used in individual suspension, substitution the 120-pound parafrag may give increased effect from low altitud For heavier damage the large fragmentation bombs or the 500-pou GP bomb may be used. For all altitudes of release a true air speed 250 miles per hour is assumed.

24. Types of Damage

The types of damage considered are casualties and normal perforati of mild steel of ⅛ inch, ¼ inch, and ½ inch thickness. A casualty defined as a hit by a fragment with at least 58 foot-pounds of energ It causes incapacitation but not necessarily death. Normal perforati of mild steel occurs when a fragment, traveling perpendicular to t face of the plate, passes completely through the plate of the indicat thickness. Damage in which there is perforation of ⅛ inch mild ste is effective against airplanes on the ground. Damage in which the is perforation of ¼ inch or ½ inch mild steel is effective against truck light armored vehicles, railway rolling stock, and targets of simil resistant nature.

25. Tables of Fragment Damage

Tables of fragment damage are given for 20- to 1,000-pound bombs tables VI to XIII. These tables give the number B of effective fra ments per square foot of target area at a given distance r from the bur The numbers B are averages for different directions from the bur These directions are restricted to side wall directions in the case bombs. They properly are applied only to a considerable number bursts with random orientation of the bomb axis relative to the targ

26. Safety Limits

The fragment damage tables are useful in determining the distance from a burst at which a soldier stands a given chance of being wounded by a fragment. Suppose, for example, that a soldier is required to take a 1 – 1,000 chance of being wounded by a fragment from a 20-pound bomb. Suppose that the soldier is in open terrain in such a position that a 2 square foot area of his body is exposed to fragments coming directly from the bomb. Accordingly, the number of casualty producing fragments, per square foot, to which the soldier is exposed is $1/1{,}000 \times \frac{1}{2} = 0.0005$ and by table VI this fragment density occurs at a distance somewhat greater than 300 feet from the bomb. Thus *on the average* the soldier should be a distance somewhat greater than 300 feet from the bomb. If account is to be taken of the most dangerous directions from the bomb, the *average densities B of effective fragments as given in the tables* should be multiplied by a factor of about six and then used as in the above example. In the case of a man in an airplane wearing standard flyer's body armor, a fragment capable of piercing the plane fuselage, the body armor, and then wounding a man, would be capable of perforating ⅛ inch mild steel. Safety limits relative to hits of this type may be found by using the tables for perforations of ⅛ inch mild steel in the manner indicated in the above example.

27. Damage Patterns

As distinguished from fragment damage tables, the damage patterns (figs. 34 – 53) represent typical individual cases and vary with the remaining velocity of the bomb, angle of fall, and the height of burst. *Both fragment damage tables and damage patterns presuppose a graze or air burst with no shielding of the target.* The user of the data given here must make due allowance for target shielding and the penetration of the bomb into the ground before burst. The amount of this penetration will depend upon the remaining velocity, the angle of fall of the bomb, the nature of the soil, the type of bomb, and the fuze. In the fragment damage pattern, shadings of different types indicate regions of decreasing density of hits. The regions distinguished are those where there is at least one hit per 1, 4, 10, or 25 square feet of area. These units of area are understood as normal to the fragment trajectories. *Unshaded regions entering near the burst do not indicate that there are no effective hits in these regions, but merely that the density of effective hits is less than that belonging to the nearest shaded area. The white centers of the fragment patterns are used to indicate the origin of the polar system above which the missile bursts. In general, these areas suffer the highest type of fragment damage as well as blast damage.* (See sec. IV, ch. 2.)

28. Bomb Density: Ground Bursts

a. The Problem. Let a target be given in terms of units of area 1 feet × 100 feet, that is, multiples of 10,000 square feet. Let it required to wound 50 percent of the enemy personnel (each 4.5 squa feet of area) on the given target area or to damage 50 percent matériel target elements (2 square feet of area) vulnerable to fragmer of a given perforative type. Table XIV gives the number D of bom of a given type required per unit of target area (10,000 square fee for several altitudes of release. Values of D are calculated for pla speed of 250 miles per hour.

b. Target Area and Fringe. To obtain the desired effect it is nece sary to distribute the bombs over an area somewhat larger than tl given target area. The fringe of additional area around the given targ area has a width W given in table XIV. This enlarged area shou receive D bombs per unit of area. Unless the edge of the target is ve well defined and of marked importance, it will usually be more profitab to confine the D bombs per unit area to the given target area A rath than use the enlarged area. In such cases points within A at a distan at least W from the edge of A will receive the desired fragment effec The calculations are based on a random distribution (any two burs are independent in position) of bombs over the enlarged area with a expected bomb density D. The manner of achieving this bomb distribu tion will depend on the CEP, the plane formation, and the timing of th bomb releases and will not be discussed here, except to remark th the total number of bombs which must be dropped to obtain the bom density D on the enlarged area A will, in general, *considerably excee* D times the number of units of area (100 feet × 100 feet) in A due t errors in bombing.

c. Example. Let the target area be 500 feet × 1,000 feet and suppos it is desired to wound 60 percent of enemy personnel on the area usin 20-pound fragmentation bombs released at an altitude of 20,000 fee Suppose the terrain is flat and unshielded. *Solution*: The width W o the additional fringe of area is 65 feet according to table XIV. Thus the enlarged area is 630 feet × 1,130 feet and contains 71 units o area. For each of these units 0.73 bombs are required in accordanc with the table. When the percent of wounded is to be 60 instead of 50 a multiplicative factor of 1.32 is called for as given in the table. Thu the number of bombs which should be distributed over the enlarge area is $0.73 \times 71 \times 1.32 = 69$. The number to be dropped must b properly increased to take account of probable errors in bombing.

d. Matériel Targets. In the case of enemy *matériel* each target i supposed divided into a number of elements each 2 square feet in are and vulnerable to a hit of a given perforative type, that is, perforation

of ⅛ inch, ¼ inch, or ½ inch mild steel. The table gives the number D of bombs per unit target area required to effectively damage 50 percent of these target elements. For example, an enemy vehicle may present eight of these target elements vulnerable to hits capable of perforating ⅛ inch mild steel. If the bomb density is D per unit area as given in table XIV, four of the eight target elements may be expected to be damaged effectively. As in the case of casualties, the distribution of bombs with the density D must be made over an area somewhat larger than the given target area. The width W of this additional fringe of area is given in the tables.

e. Percentage Correction. If the percent p of target elements which it is desired to damage effectively is not 50 percent, it is sufficient to multiply the bomb density given in the table by the factor F, given in the same table, to obtain the correct bomb density D.

f. Correction for Shielding. The bomb densities D are calculated for instantaneous ground bursts, flat unshielded terrain and, in the case of personnel, for men who are standing. For prone men or for terrain which is rolling or shielded, the bomb densities should be multiplied by appropriate factors. Estimates for some of the more important cases are—

The tactical case	*Factor*
Casualties	
Men prone, flat terrain, no shielding	3
Men standing, rolling terrain, no shielding	2
Men prone, rolling terrain, country fields	4
Men firing from trenches	10–20
Men in foxholes	20–100
Penetration	
Rolling terrain, no shielding	2
Rolling terrain, rough country	3

g. Blast. Blast is effective against personnel in the open for relatively small distances, in every case for distances considerably less than those at which a casualty is certain to be caused by fragments (see sec. IV, ch. 2).

29. Air Bursts

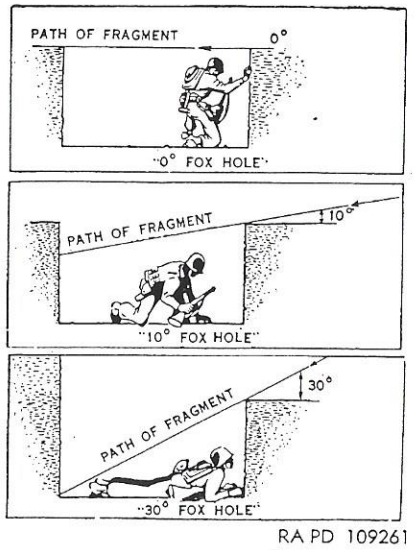
a. Against personnel in medium foxholes or on rough terrain, or against other moderately shielded targets, an air burst of the 500-pound GP bomb, AN–M64 or AN–M64A1, or the larger size fragmentation bomb (220-pound or more) is recommended. A height of burst from 35 to 60 feet would be effective, with the higher burst counteracting

the greater shielding. Released from an altitude of 15,000 feet or more, the 20 pound fragmentation bomb, AN–M41 or AN–M41A1, with impact type fuze, is diminished in fragment damage not only from the effects illustrated in the damage patterns (fig. 34), but also because the bomb penetrates the soil to some extent before bursting. From these altitudes an air burst of the 500-pound GP bomb, AN–M64 or AN–M64A1, or the larger size fragmentation bomb (220-pound or more) will be highly effective.

b. Optimum Height. The optimum height of burst of a bomb depends upon the type of shielding of the targets to be attacked. In the complete absence of shielding by the terrain, by other targets, and on open, level ground, the optimum height of burst is just off the ground; to raise the height of burst still higher would cause a loss of effect approximately as follows:

Height of burst	*Percent loss in targets effectively damaged*
30 ft	5–15
50 ft	25-50
100 ft	70–80

c. Types of Shielding. Air bursts are recommended against men in foxholes or open trenches and against personnel shielded by rough terrain. The type of shielding labeled "10° foxholes" is believed to be that most commonly encountered and will correspond to the shielding



TYPES OF SHIELDING

Figure 33. Types of shielding.

afforded men in foxholes when the men are somewhat below the level of the ground (fig. 33), or to the shielding afforded prone men by rough terrain. The term "10° foxhole" arose from its definition as a foxhole in which an occupant will, on the average, be unharmed by fragments with an angle of fall less than 10 degress. Hastily dug in positions on level ground will correspond to "0° foxholes," as will trenches in which the heads of men are even with the ground.

d. Use of Charts. The optimum heights of burst against personnel in the absence of dispersion in the height of burst may be read from figures 54 to 58. From these figures one reads the number of casualties against the height of burst assuming that there is one man in each foxhole and that the foxholes are ten feet apart. The terminal velocities for which these curves are drawn are based on a true air speed of 400 miles per hour. For the angles of fall indicated on figures 54 to 58 the curves will not be changed materially if the true air speed is reduced to as low as 250 miles per hour.

e. Dispersion. When a fuze for regulating the height of burst is available and causes a known dispersion in the height of burst, it is possible to use figures 54 to 58 to determine the *mean height* to which the burst should be adjusted, as is done in the case of time fire with shell. This mean optimum height in the case of dispersion is in general larger than the optimum heights read from the figures. As the type of shielding runs from the weak zero degree shielding to the strong 30 degree shielding, the optimum heights of burst run approximately as follows:

Bomb	*Optimum height of burst No dispersion 0 degrees to 30 degrees shielding*
20-lb bomb AN-M41 or AN-M41A1	20 ft–30 ft.
90-lb bomb M82	30 ft–50 ft.
100-lb bomb AN-M30 or AN-M30A1	30 ft–50 ft.
260-lb bomb AN-M81	35 ft–70 ft.
500-lb bomb AN-M64 or AN-M64A1	30 ft–60 ft.

This optimum height is greater, the greater the shielding. In the case of heavy shielding, low bomb angles of fall (around 45 degrees) are superior to high bomb angles of fall (around 75 degrees). For average shielding, the angles of fall (45 degrees–75 degrees) do not affect the result to any considerable degree. Computations show that a tail initiation of the burst would more than double the effect in the case of low shielding and high angle of fall.

Table V. Fragmentation Comparison: Ratios of Effective Hits Obtained fro Various Bomb Combinations at Various Altitudes of Release

No. and type of bombs compared	Altitude of attack	Ratio of fragments from bombs compared causing			
		Casualties	⅛" perf	¼" perf	½" perf
Six 20-lb frag	Low*	1.83	2.38	0.94	....
One 100-lb GP	10,000 ft	3.00	2.48	....	....
	20,000 ft	1.67	1.19	....	....
	30,000 ft	1.05	0.79	....	....
Six 20-lb frag	Low*	1.03	0.96	0.52	....
One 260-lb frag	10,000 ft	1.41	0.88	....	....
	20,000 ft	0.68	0.40	....	....
	30,000 ft	0.51	0.35	....	....
One 100-lb GP	Low	0.56	0.40	0.55	....
One 260-lb frag	10,000 ft	0.47	0.35	0.49	....
	20,000 ft	0.41	0.33	0.47	....
	30,000 ft	0.48	0.44	0.61	....
Twenty 20-lb frag	Low*	1.05	1.07	0.69	....
Six 90-lb frag	10,000 ft	1.05	0.81	....	....
	20,000 ft	0.79	0.66	....	....
	30,000 ft	1.08	0.65	....	....
Twenty 20-lb frag	Low*	1.91	2.05	1.12	....
One 500-lb GP	10,000 ft	2.88	2.13	....	....
	20,000 ft	1.86	1.38	....	....
	30,000 ft	1.46	0.99	....	....
Six 90-lb frag	Low*	1.81	1.92	1.45	0.28
One 500-lb GP	10,000 ft	2.74	2.64	1.80	....
	20,000 ft	2.34	2.09	1.32	....
	30,000 ft	1.36	1.51	0.98	....
Two 100-lb GP	Low	0.79	0.65	0.67	....
One 500-lb GP	10,000 ft	0.78	0.66	0.68	....
	20,000 ft	0.85	0.71	0.74	....
	30,000 ft	0.93	0.75	0.78	....
Two 260-lb frag	Low	1.42	1.61	1.21	0.85
One 500-lb GP	10,000 ft	1.65	1.87	1.39	0.98
	20,000 ft	2.09	2.14	1.58	1.13
	30,000 ft	1.91	1.70	1.27	0.91

*For low altitude bombing, the effectiveness of fragmentation bombs will be greatly increas if the parafrag (23-lb M40 or 120-lb M86) is substituted for the corresponding fin-stabilized-fr

Table VI. Fragment Damage: Casualty and Perforation Effectiveness of Bomb, Fragmentation, 20-lb, AN-M41 or AN-M41A1; TNT Loading; Initial Fragment Velocity 2810 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	1210	.395	.0075	2810
30	1120	.162	.0115	2270
40	1060	.0865	.0162	1920
50	1000	.0522	.0218	1650
60	955	.0346	.0283	1450
80	885	.0181	.0426	1180
100	820	.0107	.0561	1030
150	695	.00403	.0844	839
200	590	.00192	.111	732
300	375	.00054	.172	588
400	205	.00017	.244	493
Perforations of ⅛ inch mild steel				
20	940	.307	.0308	2810
30	875	.127	.0437	2460
40	800	.0653	.0592	2210
60	620	.0225	.102	1860
80	415	.00846	.159	1620
100	232	.00303	.230	1460
120	105	.00095	.312	1330
140	30	.00020	.400	1230

Table VII. Fragment Damage: Casualty and Perforation Effectiveness of Bomb, Fragmentation, 90-lb, M82; Comp B Loading; Initial Fragment Velocity 3,100 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
40	5000	.408	.0134	2100
50	4550	.238	.0183	1800
60	4050	.147	.0241	1570
80	3350	.0683	.0371	1260
100	2830	.0369	.0508	1080
150	2160	.0125	.0792	866
200	1790	.00584	.105	752
300	1380	.00200	.164	602
400	1030	.00084	.233	505
600	645	.00023	.409	381
800	400	.00008	.641	304
Perforation of ⅛ inch mild steel				
20	4100	1.34	.0236	3100
30	3480	.505	.0343	2700
40	3000	.245	.0464	2400
60	2160	.0780	.0783	2010
80	1620	.0330	.126	1750
100	1270	.0166	.184	1560
120	965	.00875	.253	1420
140	770	.00513	.331	1310
170	575	.00260	.462	1180
200	430	.00140	.607	1090
300	163	.00024	1.08	930
Perforation of ¼ inch mild steel				
20	1250	.408	.186	3100
30	1050	.152	.226	2890
40	910	.0742	.271	2700
60	690	.0250	.375	2420
80	530	.0108	.504	2190
100	400	.00522	.645	2020
120	282	.00256	.815	1870
140	185	.00123	1.02	1740
170	89	.00040	1.34	1600
200	17	.00006	1.73	1480

Table VIII. Fragment Damage: Casualty and Perforation Effectiveness of Bomb, GP, 100-lb, AN–M30 or AN–M30A1; Amatol Loading; Initial Fragment Velocity 7,320 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
70	3880	.103	.0086	2630
80	3680	.0751	.0110	2320
100	3310	.0432	.0168	1880
120	3010	.0273	.0242	1570
140	2710	.0180	.0327	1350
170	2280	.0103	.0473	1120
200	1895	.00618	.0616	982
300	1120	.00162	.106	748
500	510	.00027	.215	526
700	229	.00006	.362	405
Perforation of ⅛ inch mild steel				
40	4070	.332	.0072	4810
50	3760	.196	.0103	4160
60	3500	.127	.0142	3700
80	3040	.0620	.0238	3090
100	2600	.0339	.0360	2660
120	2160	.0196	.0507	2330
140	1690	.0113	.0695	2100
170	1130	.00510	.105	1850
200	760	.00248	.151	1650
400	60	.00005	.686	1060
Perforation of ¼ inch mild steel				
20	3170	1.03	.0205	7320
30	2850	.413	.0285	6390
40	2540	.207	.0375	5720
60	1960	.0711	.0585	4780
80	1410	.0288	.0840	4180
100	1030	.0134	.114	3730
120	770	.00698	.149	3380
140	595	.00396	.189	3080
170	398	.00180	.260	2750
200	248	.00081	.344	2490
300	52	.00008	.742	1930

Table IX. Fragment Damage: Casualty and Perforation Effectiveness of Bomb, Fragmentation, 220-lb, AN–M88; Comp B Loading; Initial Fragment Velocity 4,420 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
40	8650	.706	.0073	2850
50	8000	.418	.0101	2420
60	7400	.268	.0134	2100
80	6500	.133	.0217	1650
100	5800	.0757	.0322	1360
150	4500	.0261	.0609	988
200	3700	.0121	.0857	832
300	2800	.00406	.137	658
500	1920	.00100	.268	471
700	1500	.00040	.446	365
1000	850	.00011	.808	271
Perforation of ⅛ inch mild steel				
20	8200	2.16	.0088	4420
30	7300	1.06	.0140	3720
40	6600	.538	.0205	3260
60	5600	.203	.0364	2640
80	4650	.0948	.0568	2240
100	3750	.0489	.0845	1970
150	2300	.0133	.188	1550
200	1750	.00571	.335	1300
300	990	.00144	.720	1040
400	420	.00034	1.14	915
600	28	.00001	2.13	770
Perforation of ¼ inch mild steel				
20	4100	1.34	.0718	4420
30	3600	.522	.0917	4040
40	3180	.259	.112	3750
60	2520	.0914	.162	3270
80	2100	.0428	.220	2910
100	1860	.0243	.289	2640
150	1350	.00783	.517	2180
200	820	.00268	.822	1870
250	330	.00069	1.22	1640
300	67	.00010	1.72	1490
Perforation of ½ inch mild steel				
20	1220	.398	.580	4420
30	1090	.158	.660	4220
40	920	.0750	.750	4020
60	650	.0236	.925	3710
80	420	.00857	1.11	3480
100	250	.00326	1.33	3260
120	120	.00109	1.55	3080
140	60	.00040	1.79	2920
170	26	.00012	2.20	2710
200	13	.00004	2.65	2530

Table X. Fragment Damage: Casualty and Perforation Effectivness of Bomb, Fragmentation, 260-lb, AN-M81; Comp B Loading; Initial Fragment Velocity 3,410 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
40	6770	.552	.0114	2280
50	6560	.343	.0156	1950
60	6400	.232	.0206	1700
80	5960	.122	.0321	1360
100	5480	.0715	.0456	1140
150	4700	.0273	.0741	895
200	4150	.0135	.0992	774
300	3280	.00476	.155	619
500	2220	.00116	.301	444
700	1620	.00043	.498	345
1000	1080	.00014	.898	257
Perforation of ⅛ inch mild steel				
20	6450	2.10	.0180	3410
30	6150	.892	.0270	2950
40	5750	.469	.0373	2620
60	5000	.181	.0633	2160
80	4100	.0836	.100	1870
100	3400	4.044	.147	1670
150	2180	.0126	.310	1330
200	1570	.00512	.518	1140
300	1000	.00145	.982	940
400	650	.00053	1.47	860
600	207	.00008	2.64	730
Perforation of ¼ inch mild steel				
20	3450	1.13	.143	3410
30	3050	.442	.175	3180
40	2750	.224	.212	2960
60	2250	.0816	.294	2630
80	1870	.0381	.395	2390
100	1570	.0205	.517	2170
150	1090	.00632	.892	1820
200	690	.00225	1.41	1570
250	370	.00077	2.04	1410
300	185	.00027	2.78	1290
Perforation of ½ inch mild steel				
20	860	.281	1.17	3410
30	770	.112	1.30	3290
40	670	.0546	1.44	3160
60	500	.0181	1.74	2950
80	370	.00755	2.04	2780
100	265	.00346	2.39	2620
120	185	.00168	2.77	2490
140	125	.00083	3.19	2380
170	68	.00031	3.86	2230
200	31	.00010	4.64	2090

Table XI. Fragment Damage: Casualty and Perforation Effectiveness of Bomb, GP, 500-lb, AN-M64 or AN-M64A1; Amatol Loading; Alternate Loading TNT; Initial Fragment Velocity 7,390 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
70	14900	.397	.0085	2640
80	14000	.286	.0107	2360
100	12300	.161	.0166	1890
150	9000	.0522	.0369	1270
200	6650	.0217	.0611	986
250	5150	.0108	.0835	843
300	4100	.00595	.105	752
500	2350	.00123	.214	527
700	1290	.00034	.360	406
1000	450	.00006	.663	299
Perforation of ⅛ inch mild steel				
40	15500	1.26	.0070	4860
50	14200	.741	.0102	4180
60	13000	.471	.0139	3720
80	10800	.220	.0234	3100
100	9180	.120	.0355	2670
150	5380	.0312	.0789	2010
200	3090	.0101	.148	1660
300	1250	.00181	.370	1260
400	435	.00035	.680	1060
600	135	.00005	1.41	865
Perforation of ¼ inch mild steel				
20	11600	3.79	.0200	7390
30	10200	1.48	.0279	6440
40	8900	.726	.0367	5780
60	7000	.254	.0575	4820
80	5200	.106	.0825	4210
100	3850	.0503	.113	3740
150	2400	.0139	.208	2980
200	1400	.00457	.338	2510
300	385	.00056	.732	1940
500	87	.00005	2.15	1390
Perforation of ½ inch mild steel				
20	2900	.946	.160	7390
30	2700	.392	.180	7140
40	2300	.188	.220	6510
60	1700	.0616	.290	5790
80	1250	.0255	.370	5250
100	870	.0114	.460	4820
150	396	.00230	.720	4080
200	224	.00073	1.04	3550
250	137	.00029	1.38	3210
300	105	.00015	1.82	2900

Table XII. Fragment Damage: Casualty and Perforation Effectiveness of Bomb, SAP, 500-lb, AN–M58; AN–M58A1 or AN–M58A2; TNT Loading; Initial Fragment Velocity 5,290 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
70	6710	.179	.0133	2110
80	6380	.130	.0167	1890
100	5750	.0751	.0253	1530
150	4650	.0270	.0521	1070
200	4040	.0132	.0768	879
250	3670	.00766	.0996	772
300	3350	.00486	.125	689
500	2470	.00129	.246	491
700	1930	.00051	.414	379
1000	1350	.00018	.754	281
Perforation of ⅛ inch mild steel				
40	6700	.546	.0137	3740
50	6200	.324	.0193	3320
60	5740	.208	.0257	3010
80	5000	.102	.0409	2530
100	4400	.0574	.0604	2190
150	3220	.0187	.137	1700
200	2460	.00803	.250	1420
300	1610	.00233	.573	1110
400	1130	.00092	.960	960
600	588	.00021	1.84	795
Perforation of ¼ inch mild steel				
20	4920	1.61	.0457	5290
30	4440	.644	.0592	4770
40	4070	.332	.0750	4370
60	3500	.127	.111	3760
80	3060	.0624	.154	3340
100	2700	.0352	.204	3000
150	2050	.0119	.364	2440
200	1580	.00516	.588	2080
300	892	.00129	1.27	1620
500	175	.00009	3.44	1210
Perforation of ½ inch mild steel				
20	2040	.666	.365	5290
30	1910	.277	.420	5000
40	1800	.147	.475	4770
60	1560	.0566	.605	4360
80	1350	.0275	.750	4020
100	1190	.0155	.900	3750
150	850	.00493	1.34	3250
200	585	.00191	1.87	2870
225	484	.00125	2.17	2720
250	375	.00078	2.50	2580

Table XIII. Fragment Damage: Casualty and Perforation Effectiveness of Bomb, GP, 1,000-lb, AN–M65 or AN–M65A1; Amatol Loading; Initial Fragment Velocity 7,390 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
70	21900	.583	.0085	2640
80	19800	.404	.0107	2360
100	15800	.206	.0166	1890
150	10600	.0615	.0369	1270
200	8400	.0274	.0611	986
250	7200	.0150	.0835	843
300	6320	.00916	.105	752
500	3750	.00196	.214	527
700	2290	.00061	.360	406
1000	1250	.00016	.663	299
Perforation of ⅛ inch mild steel				
40	24000	1.96	.0070	4860
50	20200	1.05	.0102	4180
60	17400	.631	.0139	3720
80	13200	.269	.0234	3100
100	10800	.141	.0355	2670
150	7400	.0429	.0789	2010
200	5020	.0164	.148	1660
300	2200	.00319	.370	1260
400	1210	.00099	.680	1060
600	454	.00016	1.41	865
Perforation of ¼ inch mild steel				
20	14500	4.73	.0200	7390
30	12200	1.77	.0279	6440
40	10600	.865	.0367	5780
60	9400	.341	.0575	4820
80	7300	.149	.0825	4210
100	6000	.0783	.113	3740
150	3880	.0225	.208	2980
200	2460	.00803	.338	2510
300	1100	.00160	.732	1940
500	245	.00013	2.15	1390
Perforation of ½ inch mild steel				
20	4720	1.54	.160	7390
30	4350	.631	.180	7140
40	3670	.299	.220	6510
60	2850	.103	.290	5790
80	2200	.0449	.370	5250
100	1750	.0228	.460	4820
150	1140	.00661	.720	4080
200	710	.00232	1.04	3550
250	467	.00098	1.38	3210
300	310	.00045	1.82	2900

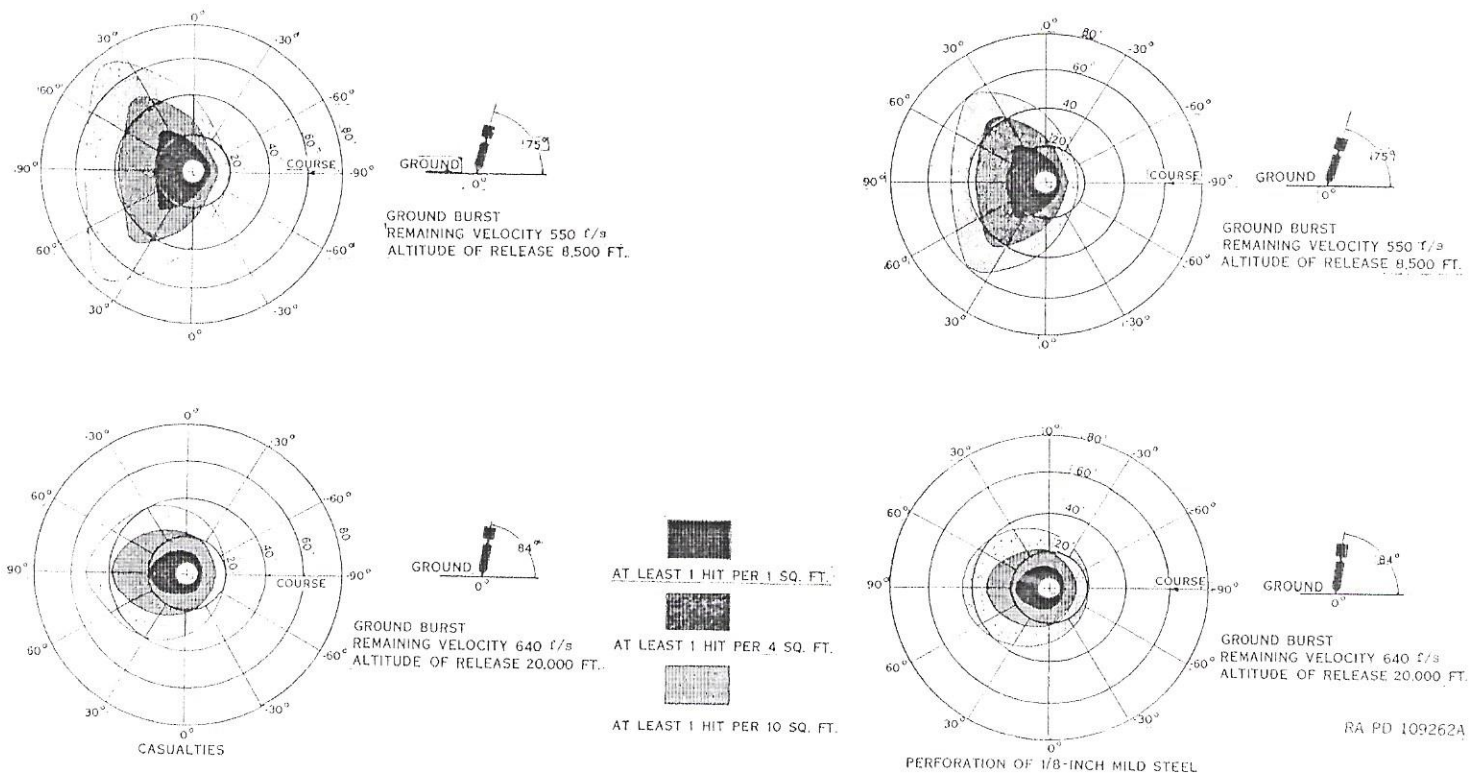


Figure 34. Damage pattern: bomb, fragmentation, 20-lb, AN-M41, AN-M41A1.

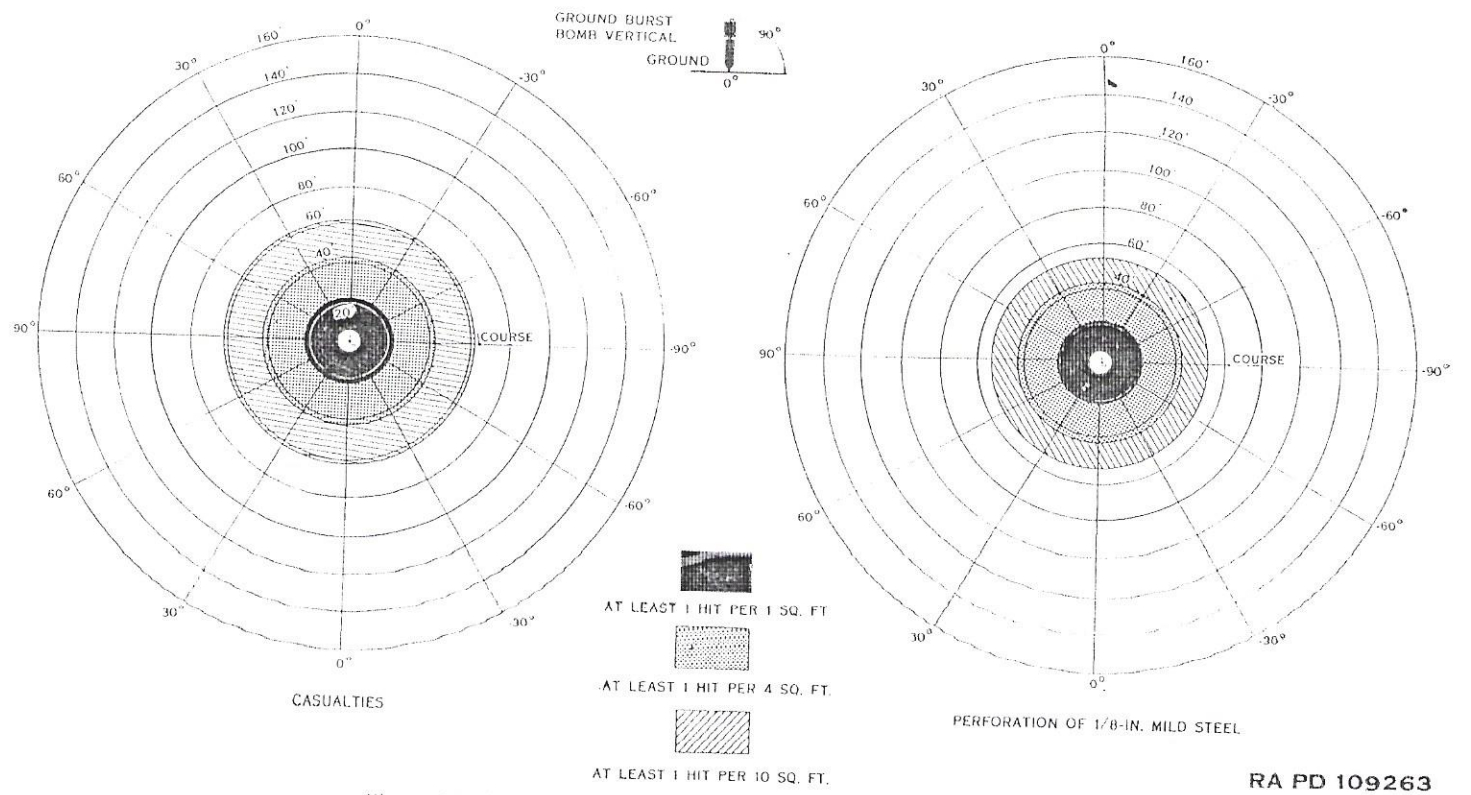


Figure 35. Damage pattern: bomb, fragmentation, 23-lb, M40, M40A1.

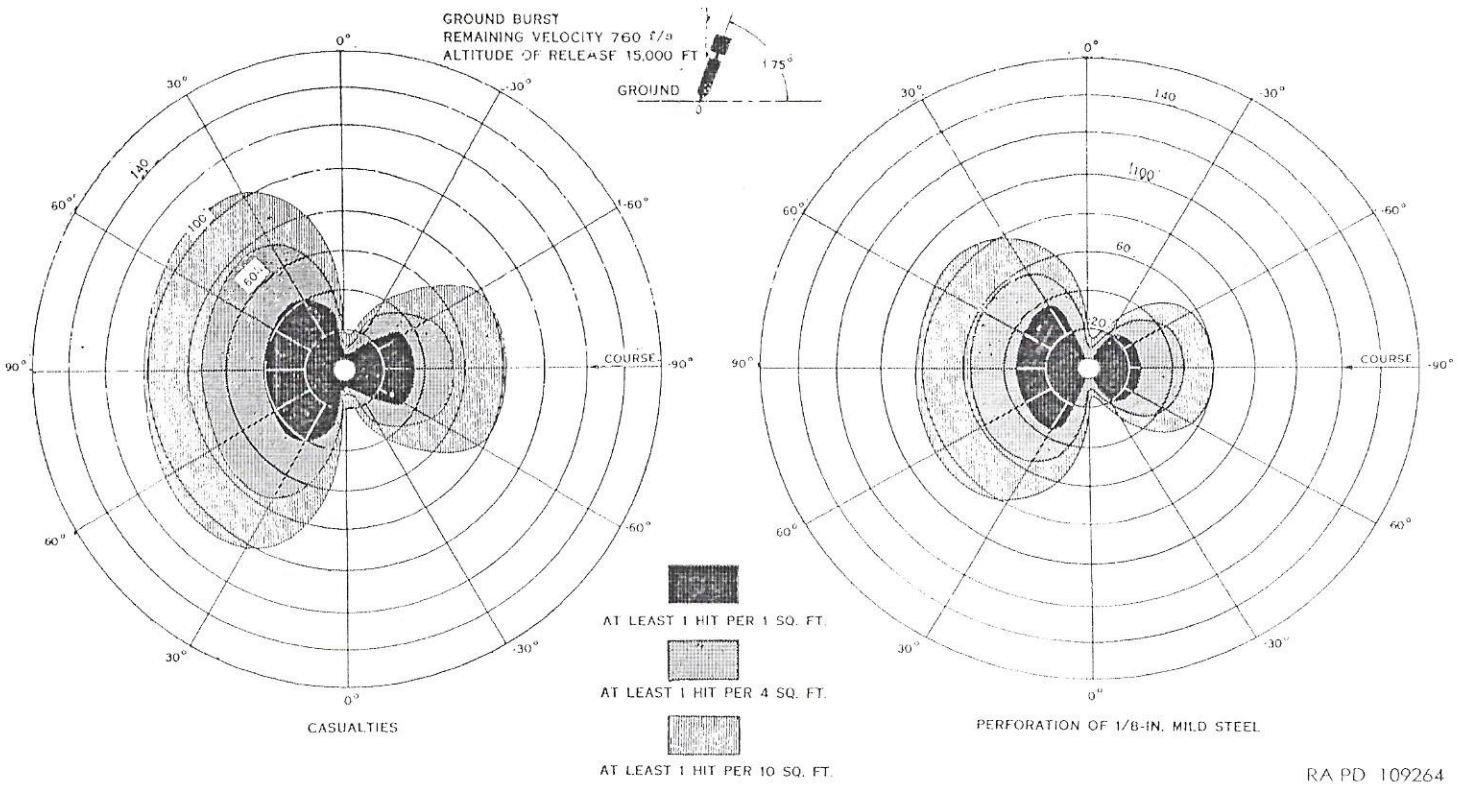


Figure 86. Damage pattern: bomb, fragmentation, 90-lb, M82.

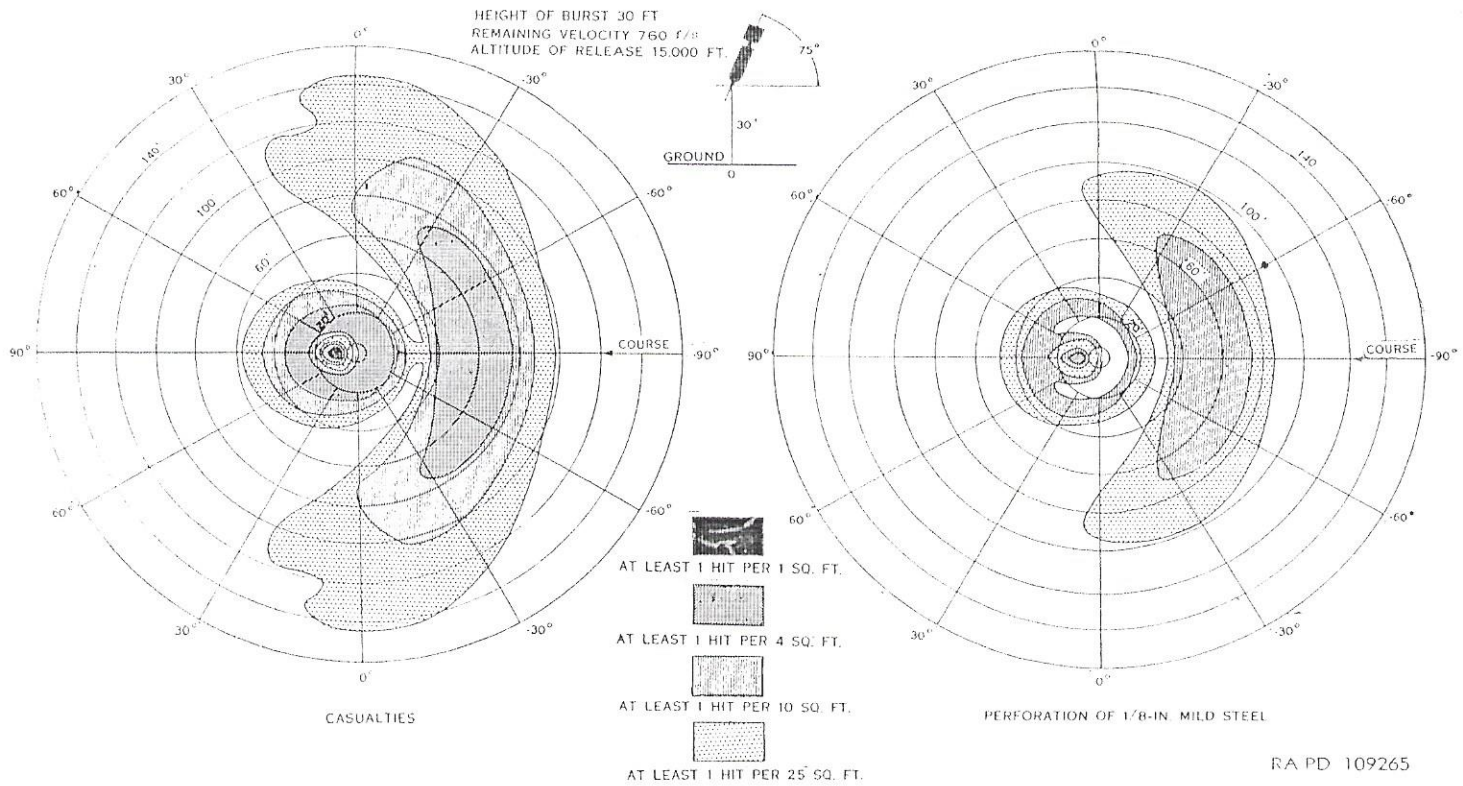


Figure 87. Damage pattern: bomb, fragmentation, 90-lb, M82.

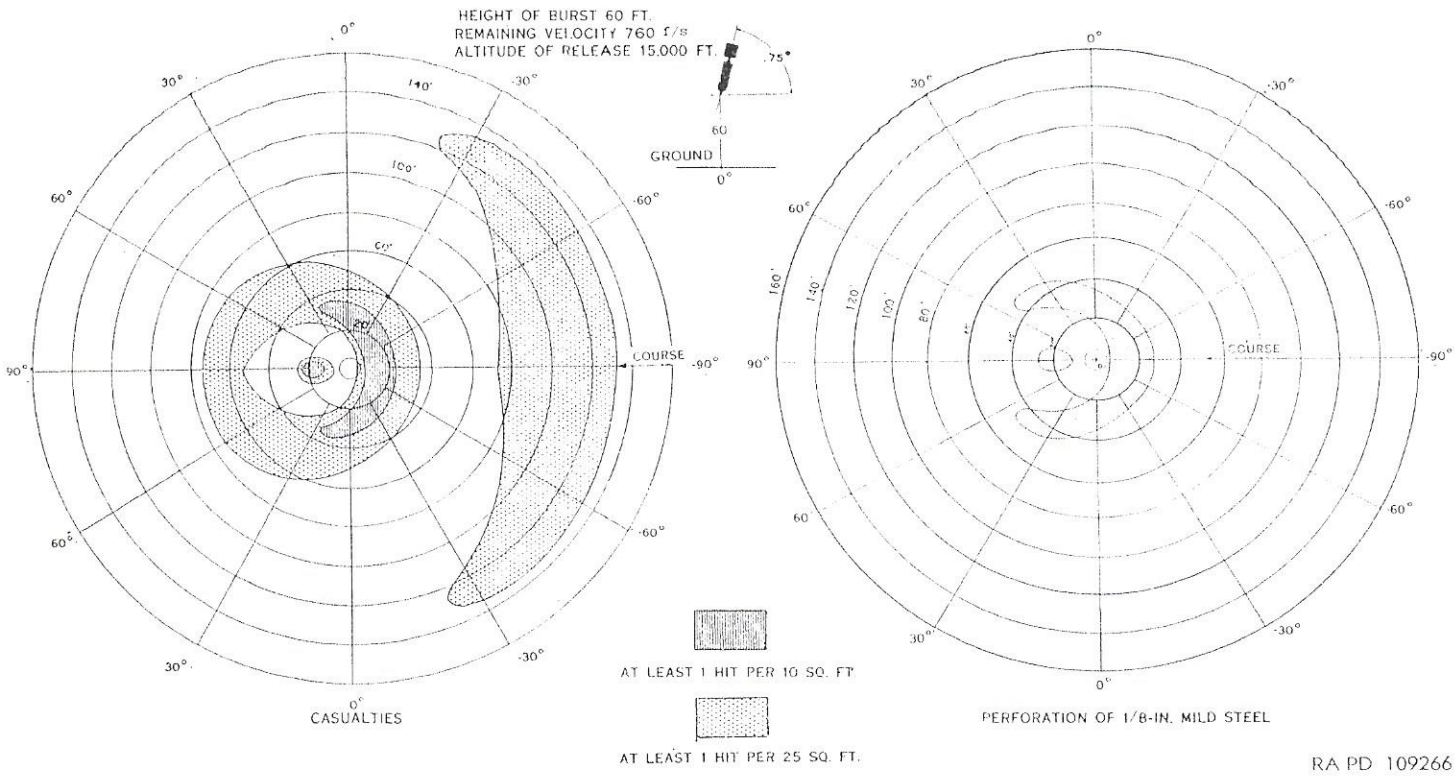


Figure 38. Damage pattern: bomb, fragmentation, 90-lb, M82.

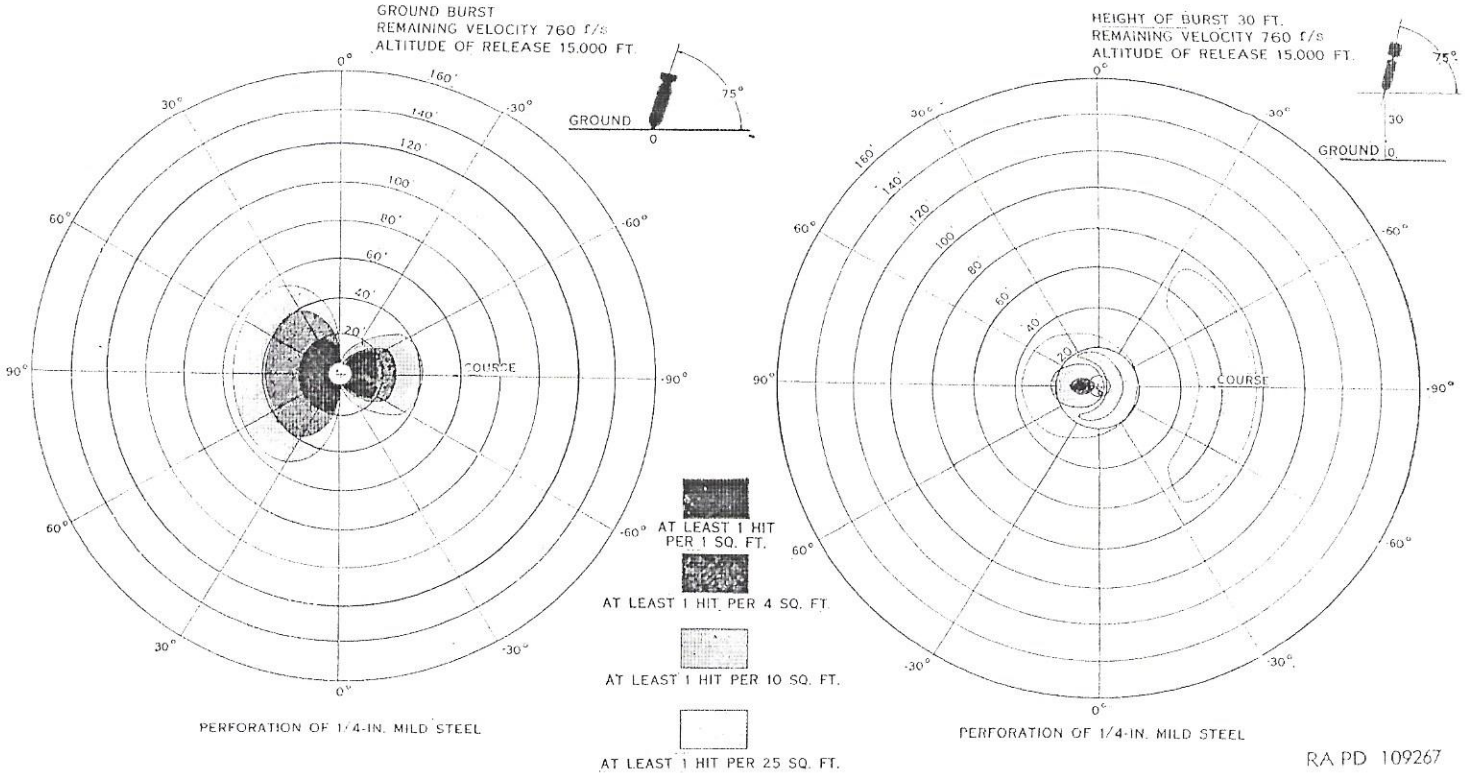


Figure 39. Damage pattern: bomb, fragmentation, 90-lb, M82.

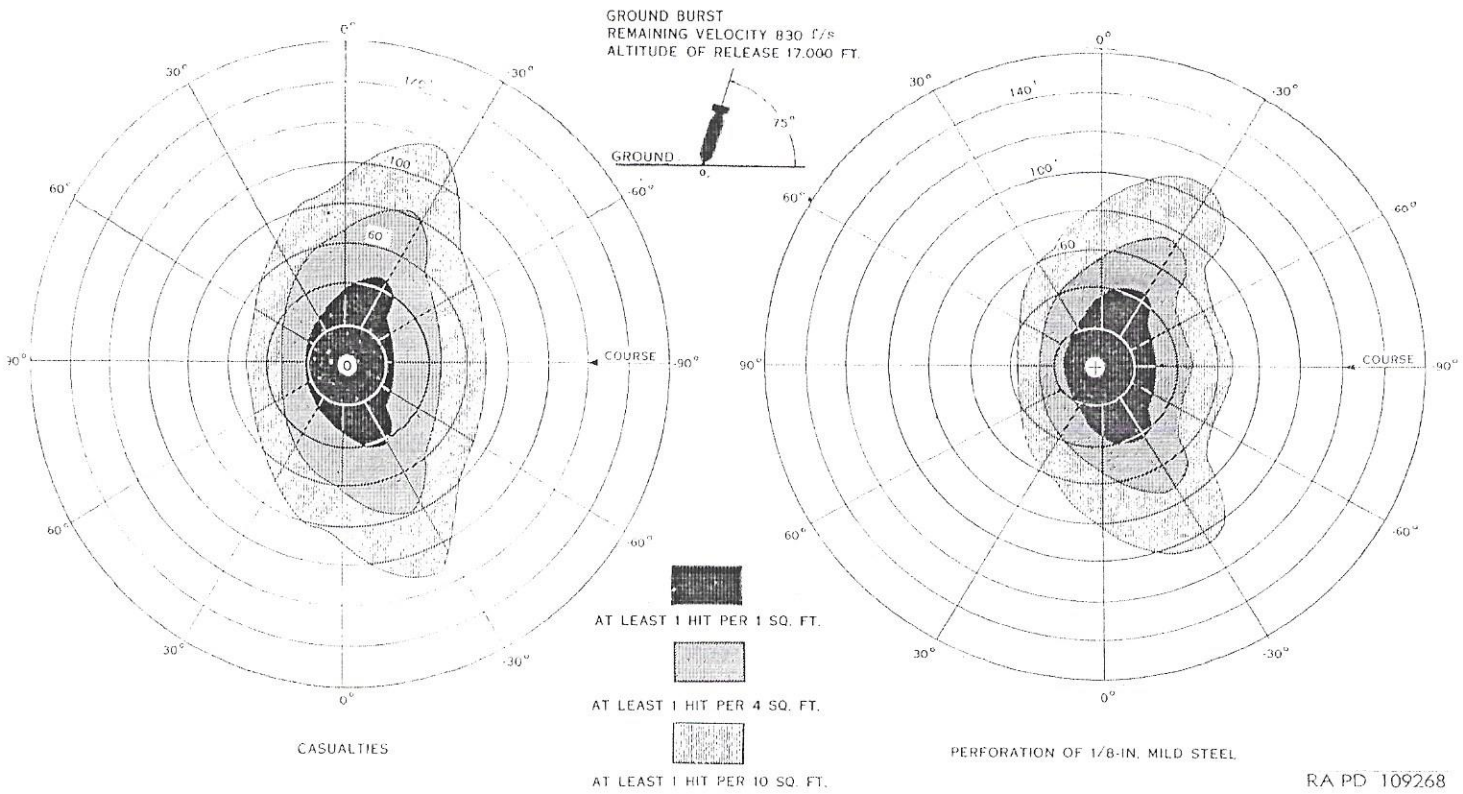


Figure 40. Damage pattern: bomb, GP, 100-lb, AN-M30 or AN-M30A1.

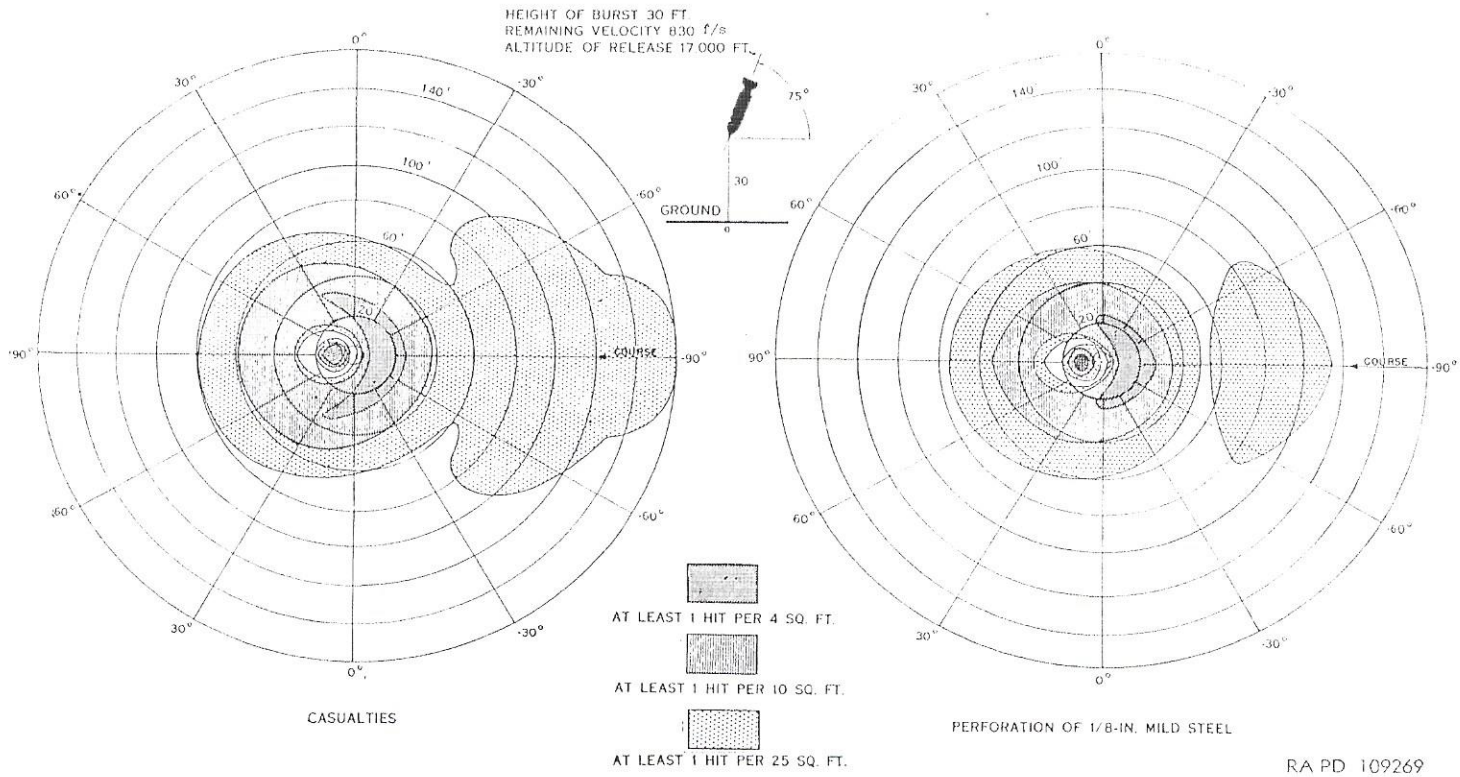


Figure 41. Damage pattern: bomb, GP, 100-lb, AN-M30 or AN-M30A1.

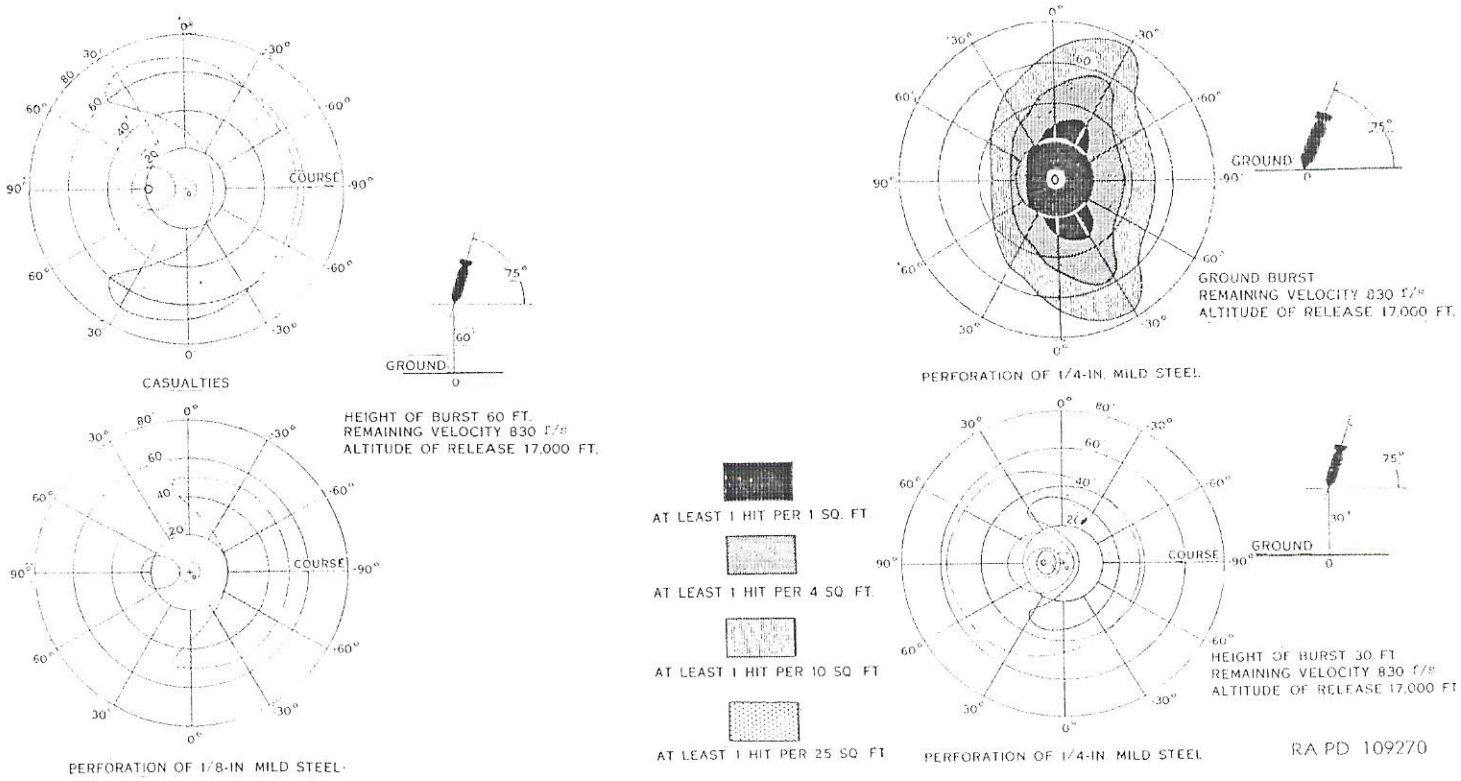


Figure 42. Damage pattern: bomb, GP, 100-lb, AN-M30 or AN-M30A1.

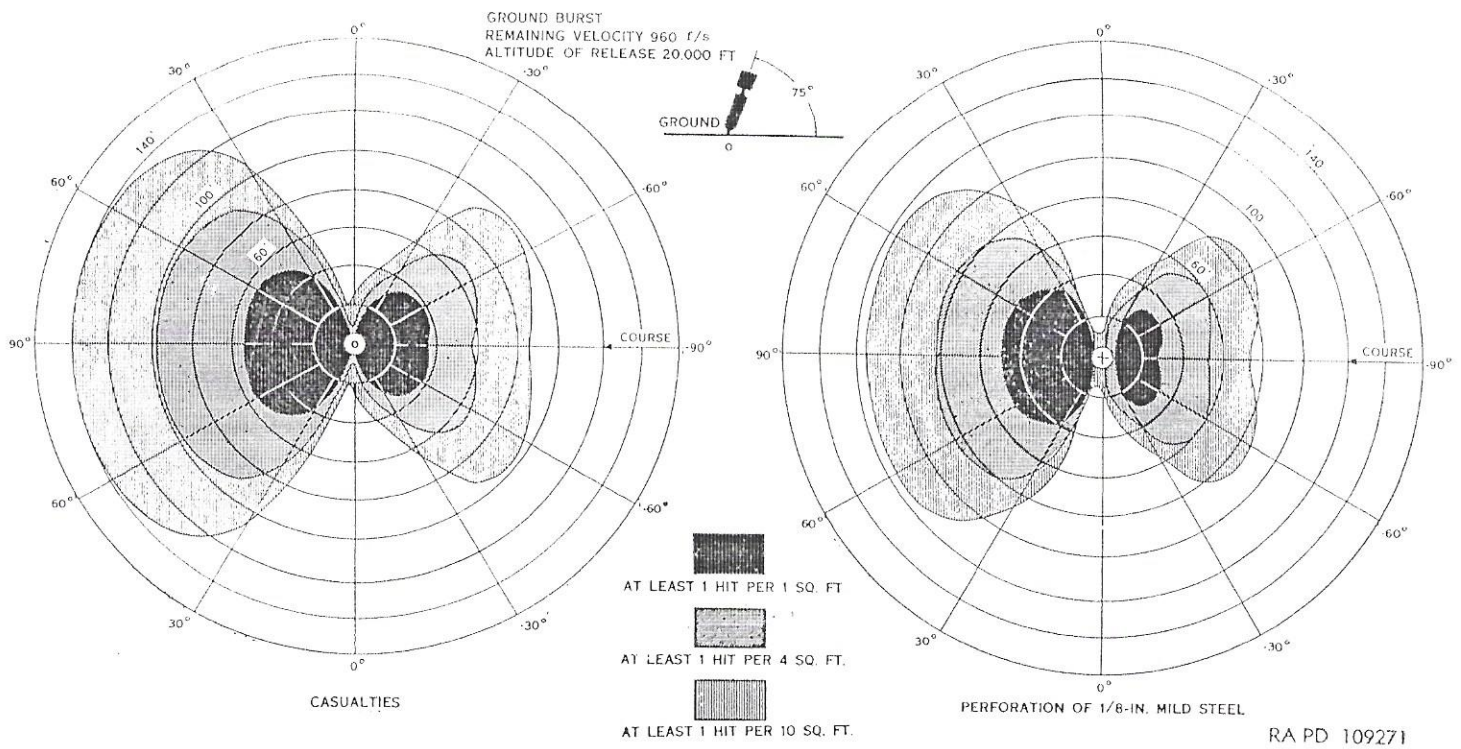


Figure 43. Damage pattern: bomb, fragmentation, 260-lb, AN-M81.

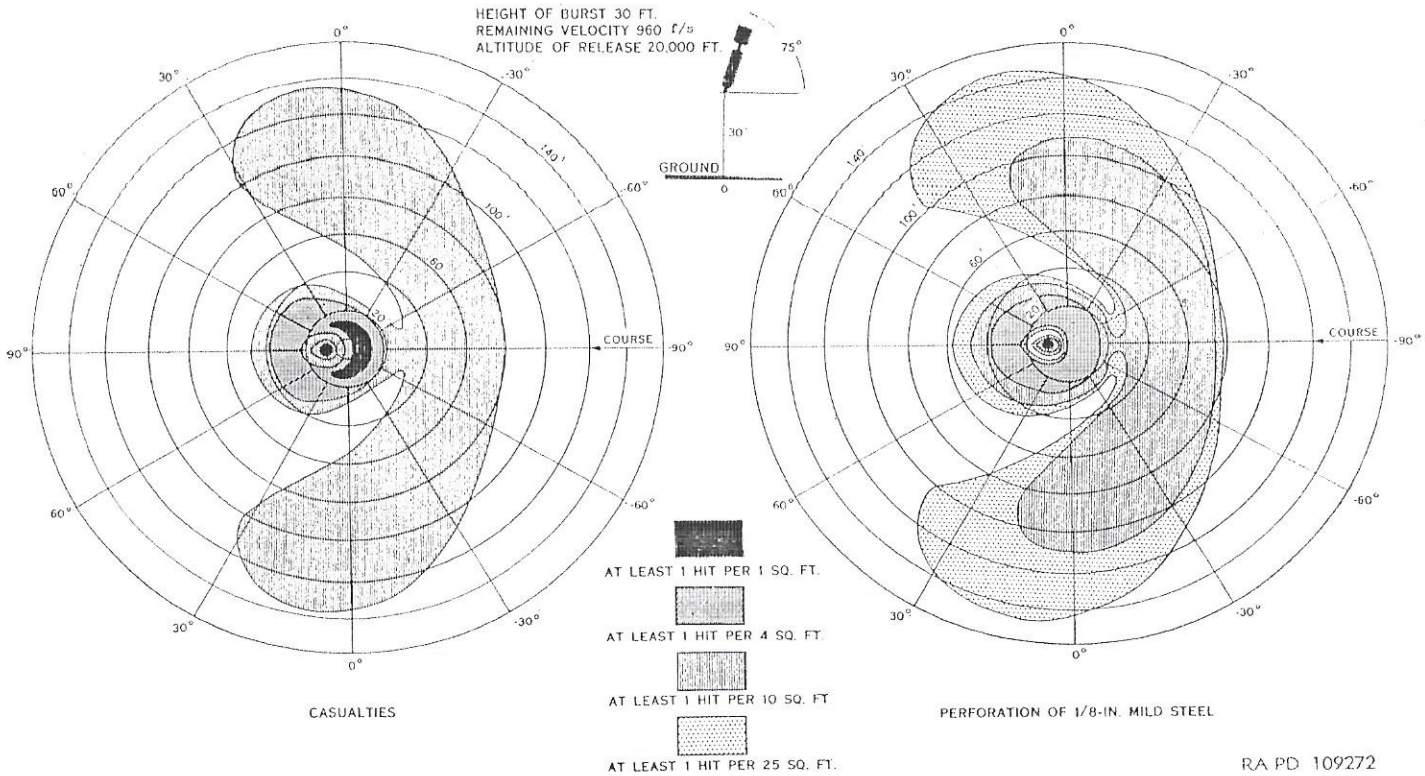
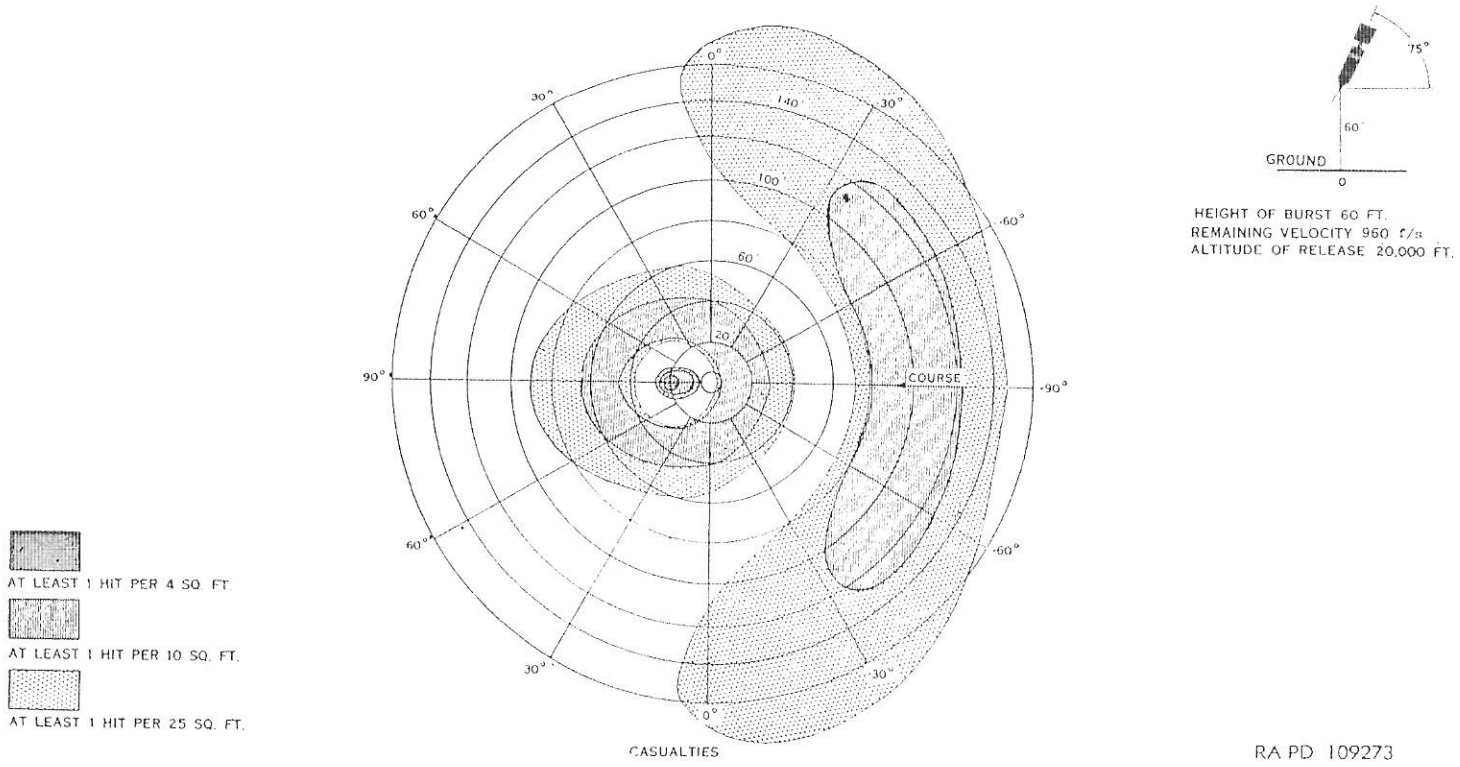


Figure 11. Damage pattern: bomb, fragmentation, 260-lb, AN-M81.



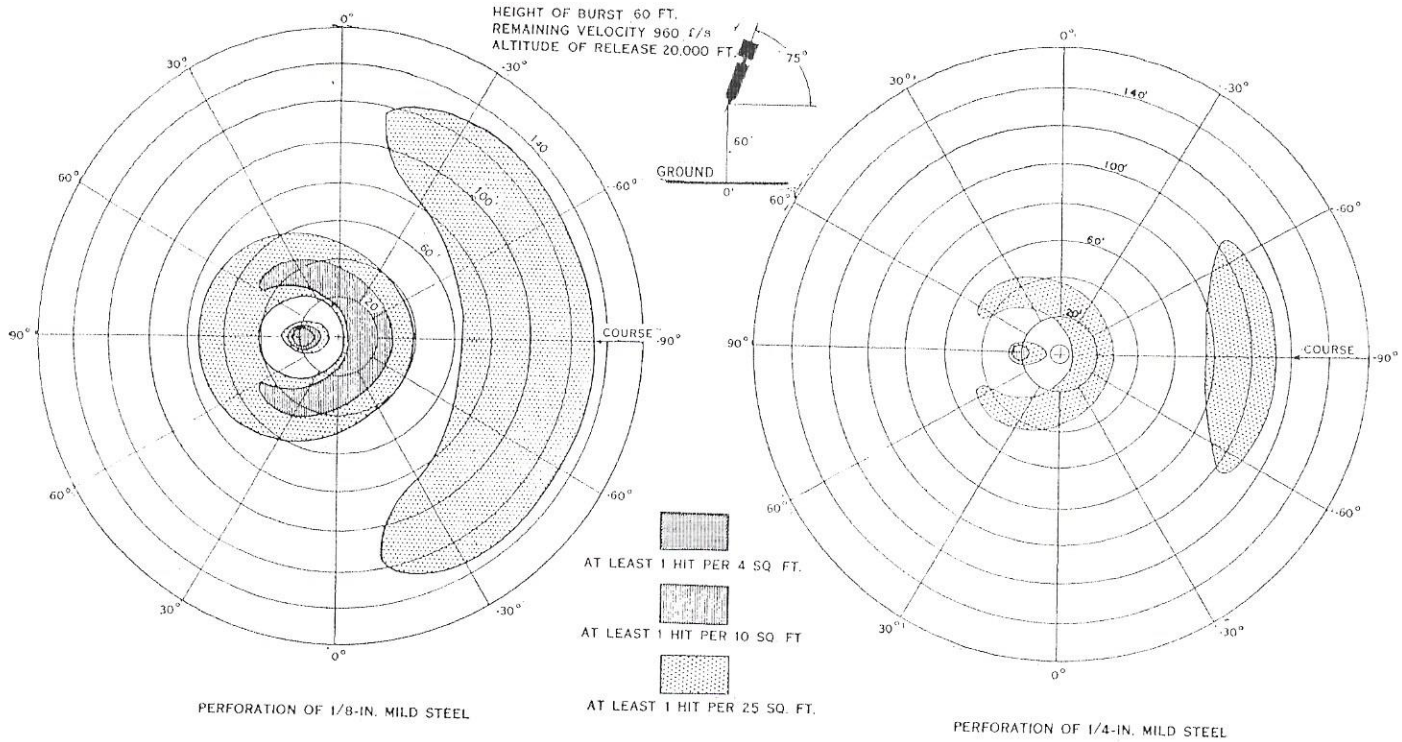


Figure 46. Damage pattern: bomb, fragmentation, 260-lb, AN-M81.

RA PD 109274

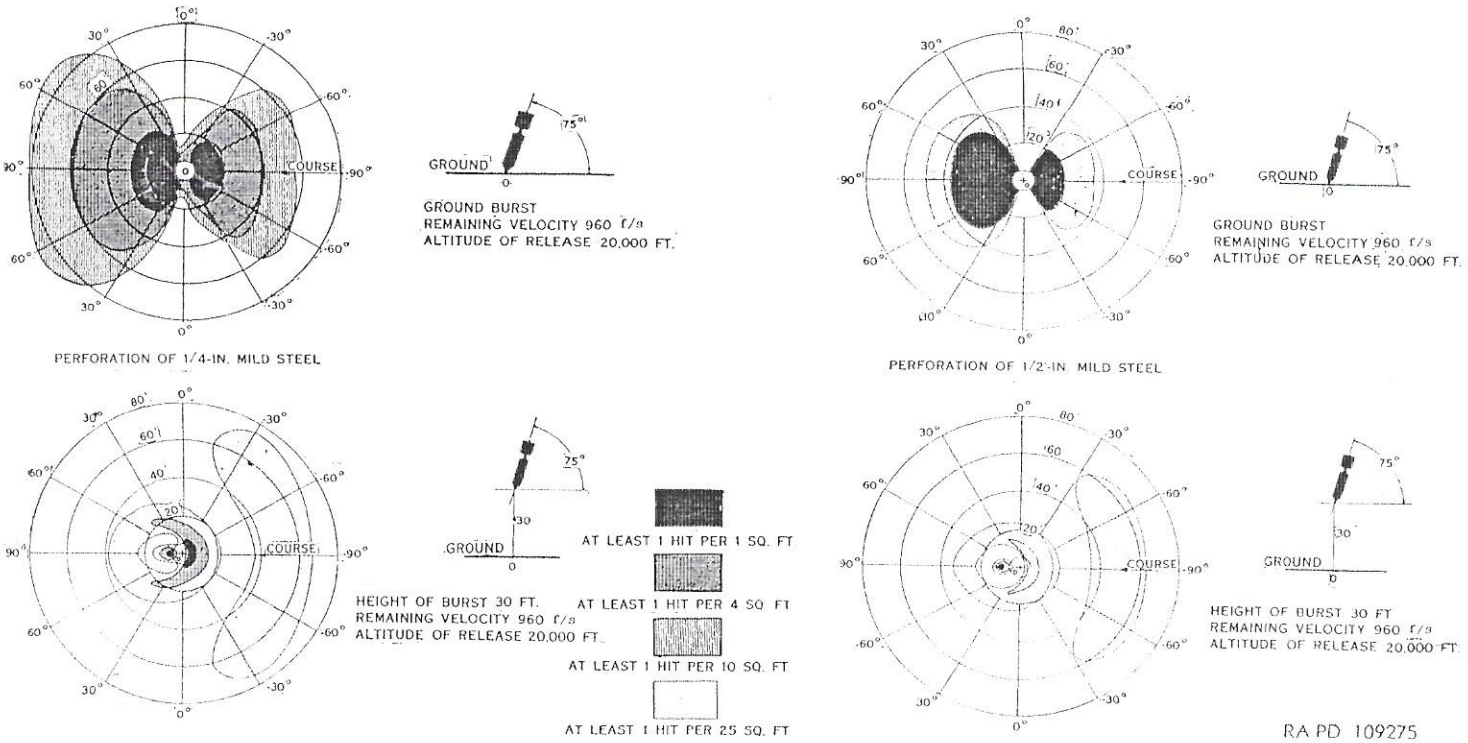


Figure 47. Damage pattern: bomb, fragmentation, 260-lb, AN-M81.

RA PD 109275

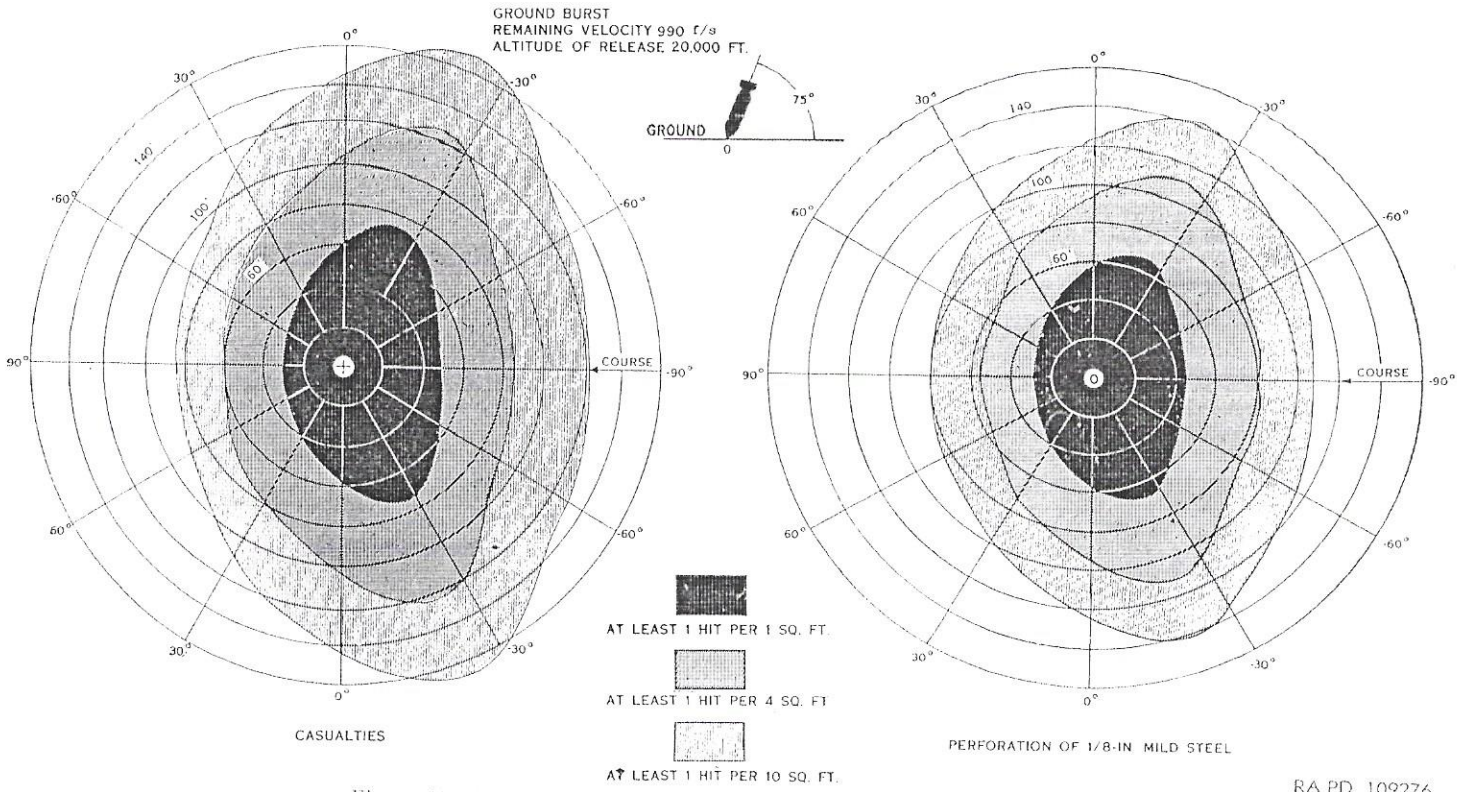


Figure 48. Damage pattern: bomb, GP, 500-lb, AN-M64 or AN-M64A1.

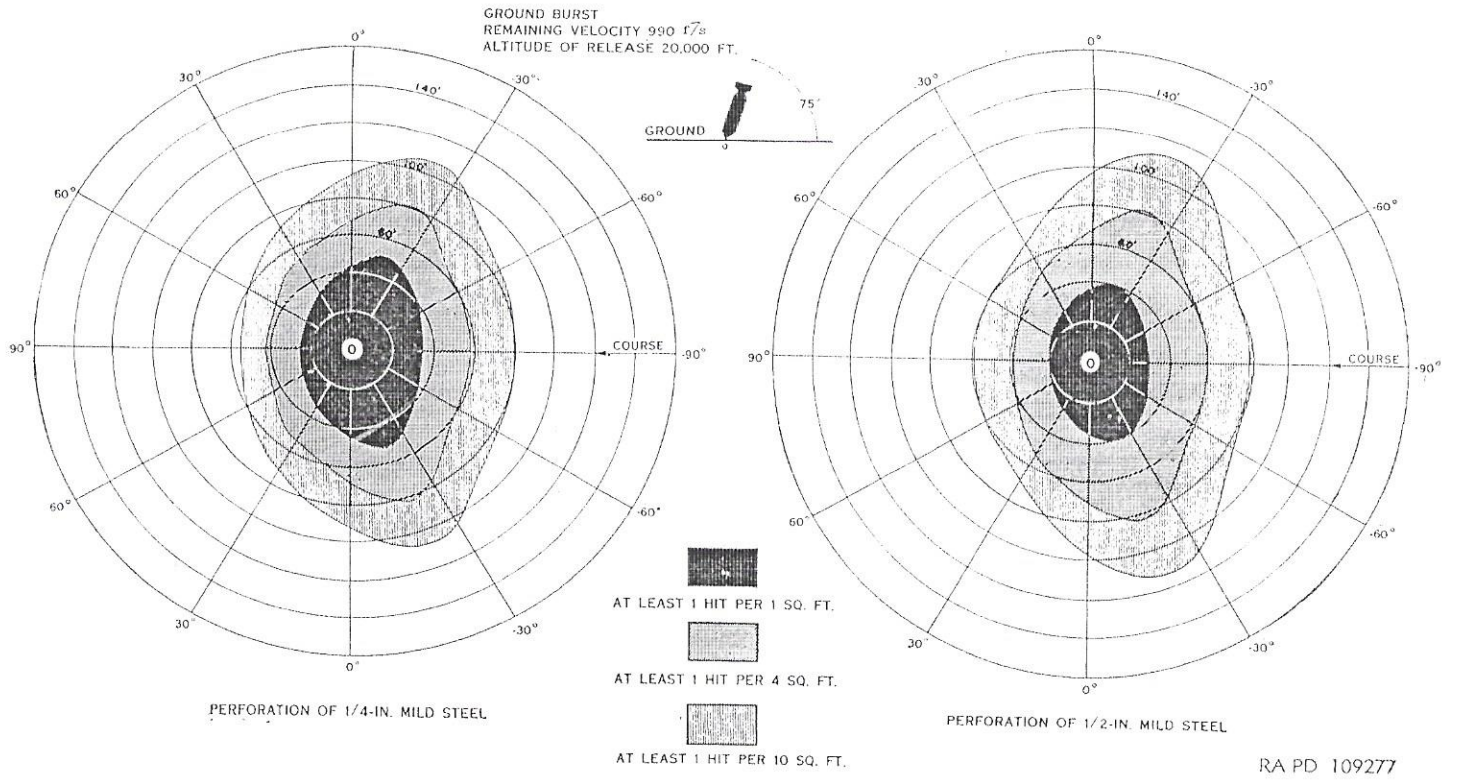


Figure 49. Damage pattern: bomb, GP, 500-lb, AN-M64 or AN-M64A1.

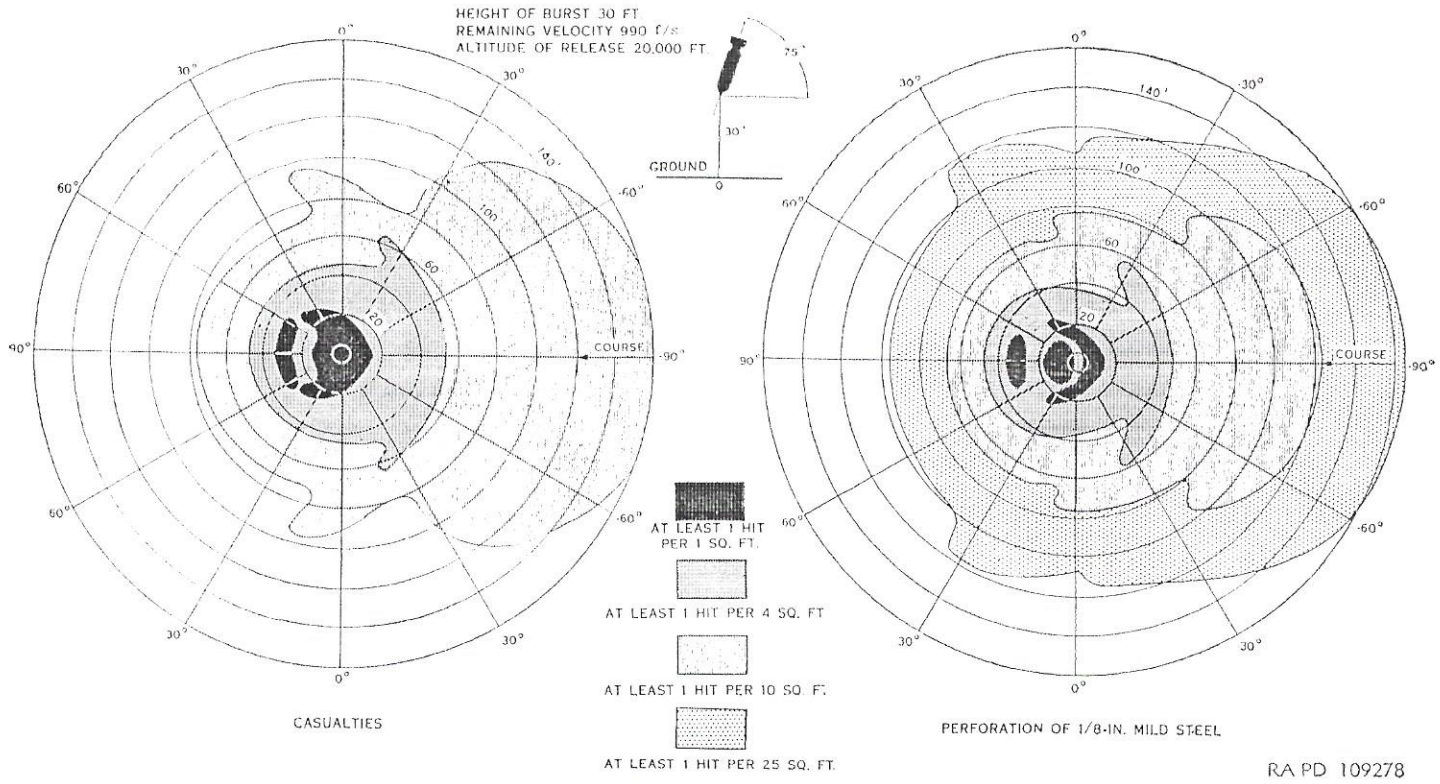


Figure 50. Damage pattern: bomb, GP, 500-lb, AN-M64 or AN-M64A1.

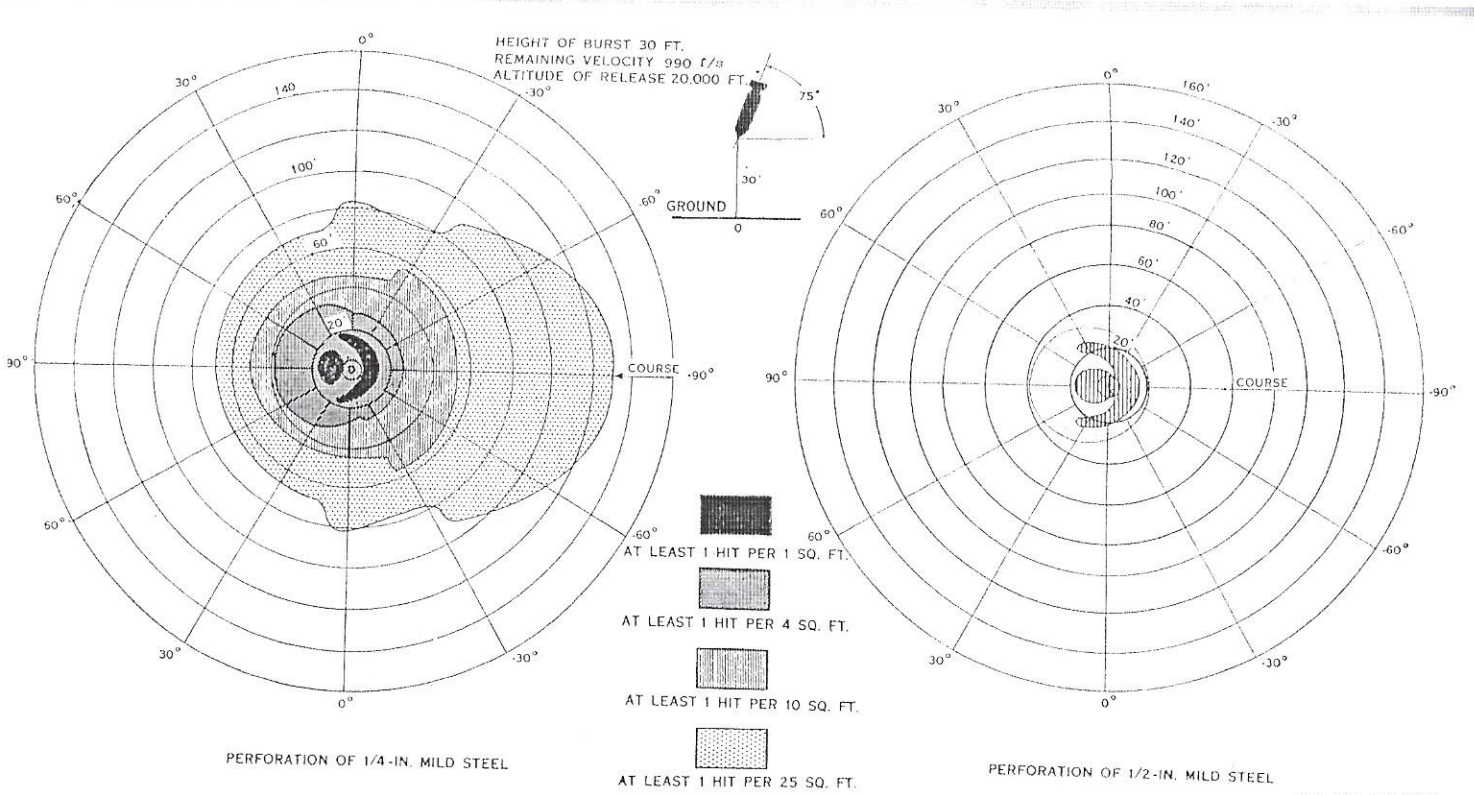


Figure 51. Damage pattern: bomb, GP, 500-lb, AN-M64 or AN-M64A1.

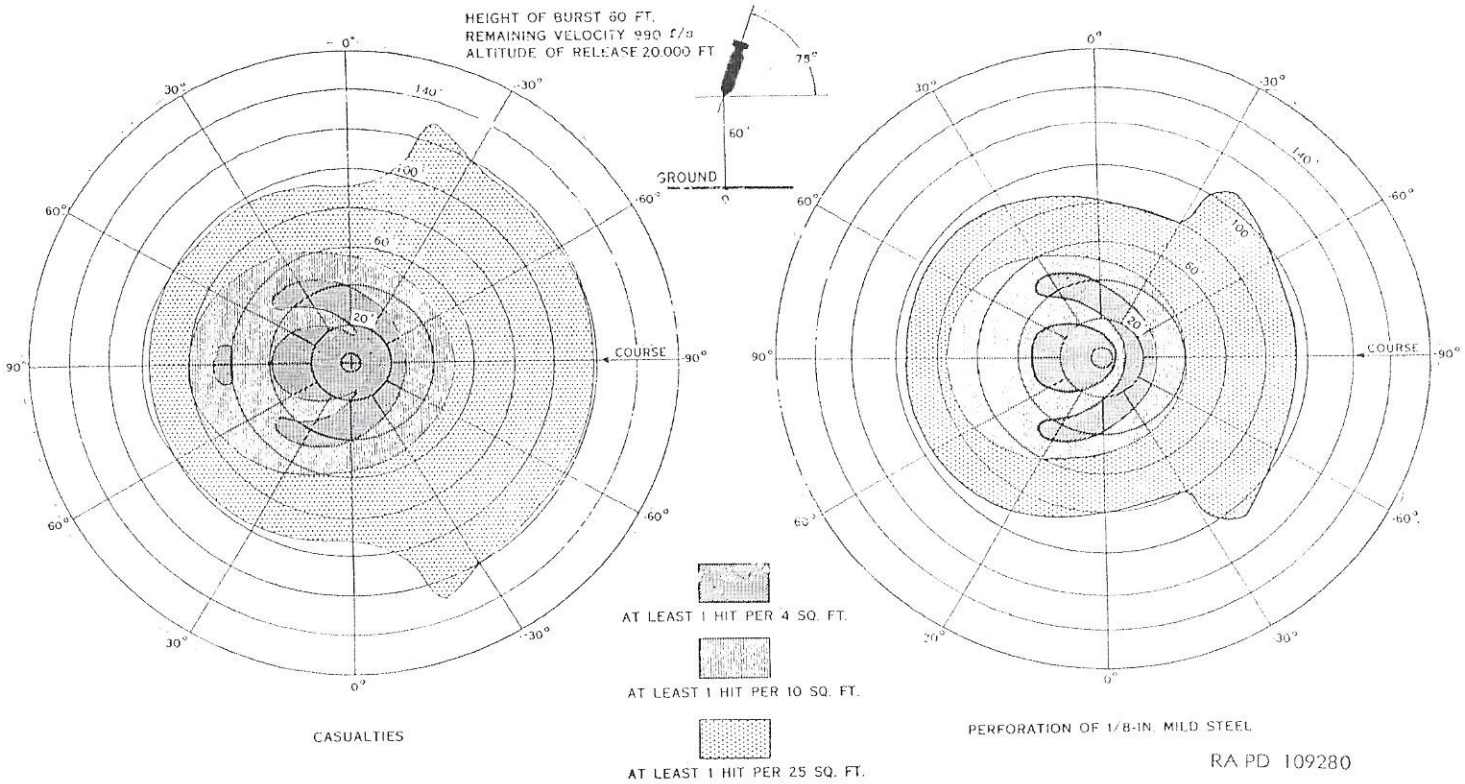


Figure 52. Damage pattern: bomb, GP, 500-lb, AN-M64 or AN-M64A1.

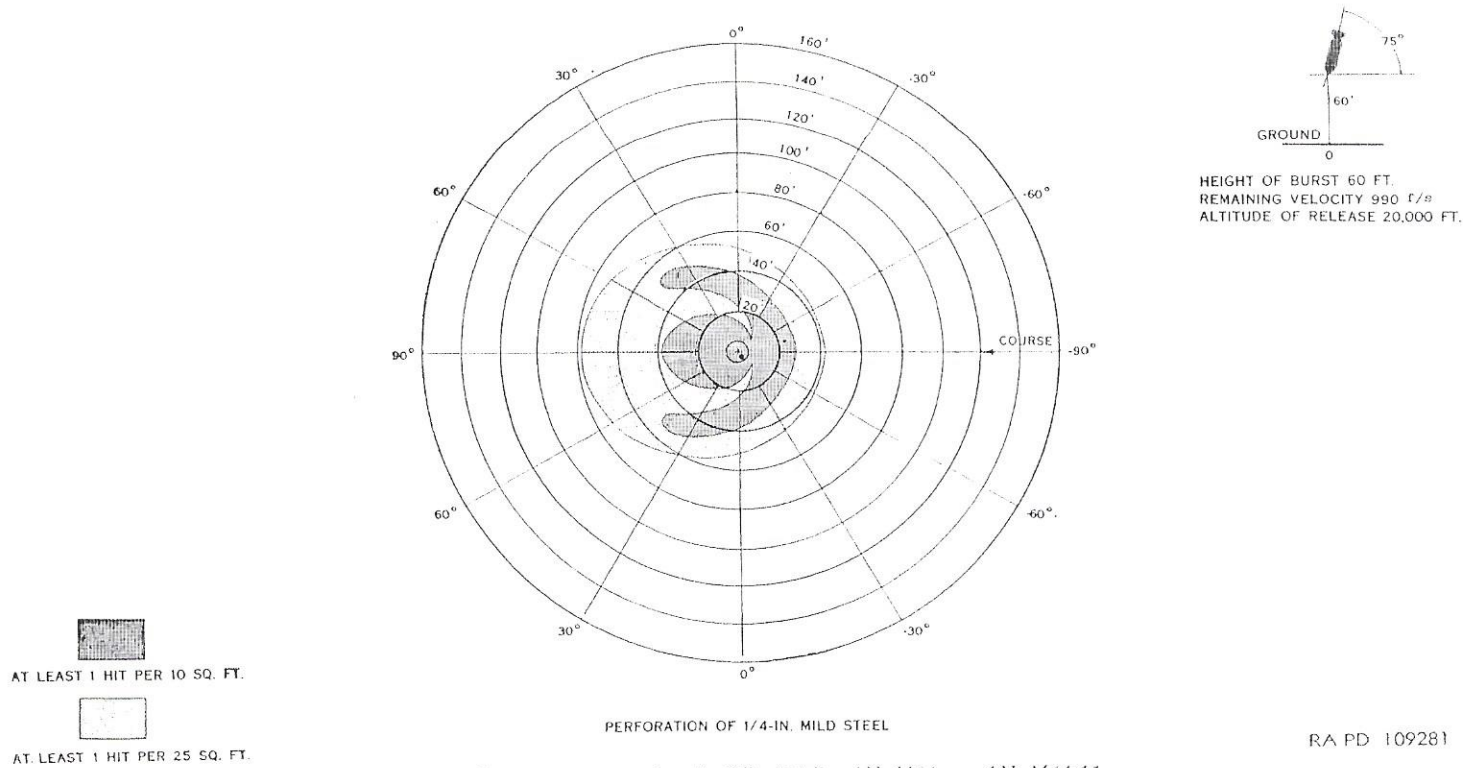


Figure 53. Damage pattern: bomb, GP, 500-lb, AN-M64 or AN-M64A1.

Table XIV. Bomb Densities per Unit Area (100′ x 100′) for Casualty and Perforation Effect

Bomb	Altitude of release ft	Casualties (50%)		Perforation of 2 sq ft target elements (50%)					
				⅛-in. mild steel		¼-in. mild steel		½ in. mild steel	
		No. bombs D	Width of fringe ft W	No. bombs D	Width of fringe ft W	No. bombs D	Width of fringe ft W	No. bombs D	Width of fringe ft W
Bomb, fragmentation, 20-lb, AN-M41 or AN-M41A1.	Low	0.70	65	2.73	27	....	....	....	....
	10,000	0.45		2.61					
	20,000	0.73		4.47					
	30,000	0.98		5.73					
Bomb, fragmentation, 90-lb, M82.	Low	0.24	90	0.99	50	1.91	30	....	....
	10,000	0.17		0.73		1.45			
	20,000	0.21		0.91		1.77			
	30,000	0.35		1.12		2.14			
Bomb, GP, 100-lb, AN-M30 or AN-M30A1.	Low	0.25	95	1.17	60	1.38	45	....	....
	10,000	0.25		1.08		1.27			
	20,000	0.20		0.89		1.06			
	30,000	0.17		0.76		0.90			
Bomb, fragmentation, 260-lb, AN-M81.	Low	0.14	140	0.47	70	0.76	55	2.41	30
	10,000	0.12		0.38		0.63		1.98	
	20,000	0.083		0.30		0.50		1.55	
	30,000	0.083		0.33		0.55		1.74	
Bomb, GP, 500-lb, AN-M64 or AN-M64A1.	Low	0.099	125	0.38	80	0.46	65	1.02	40
	10,000	0.096		0.36		0.44		0.97	
	20,000	0.087		0.32		0.39		0.88	
	30,000	0.079		0.28		0.35		0.80	

Percentage Factors

% (P)	10	20	30	40	50	60	70	80	90
Factor (F)	0.150	0.322	0.516	0.74	1.00	1.32	1.74	2.32	3.32

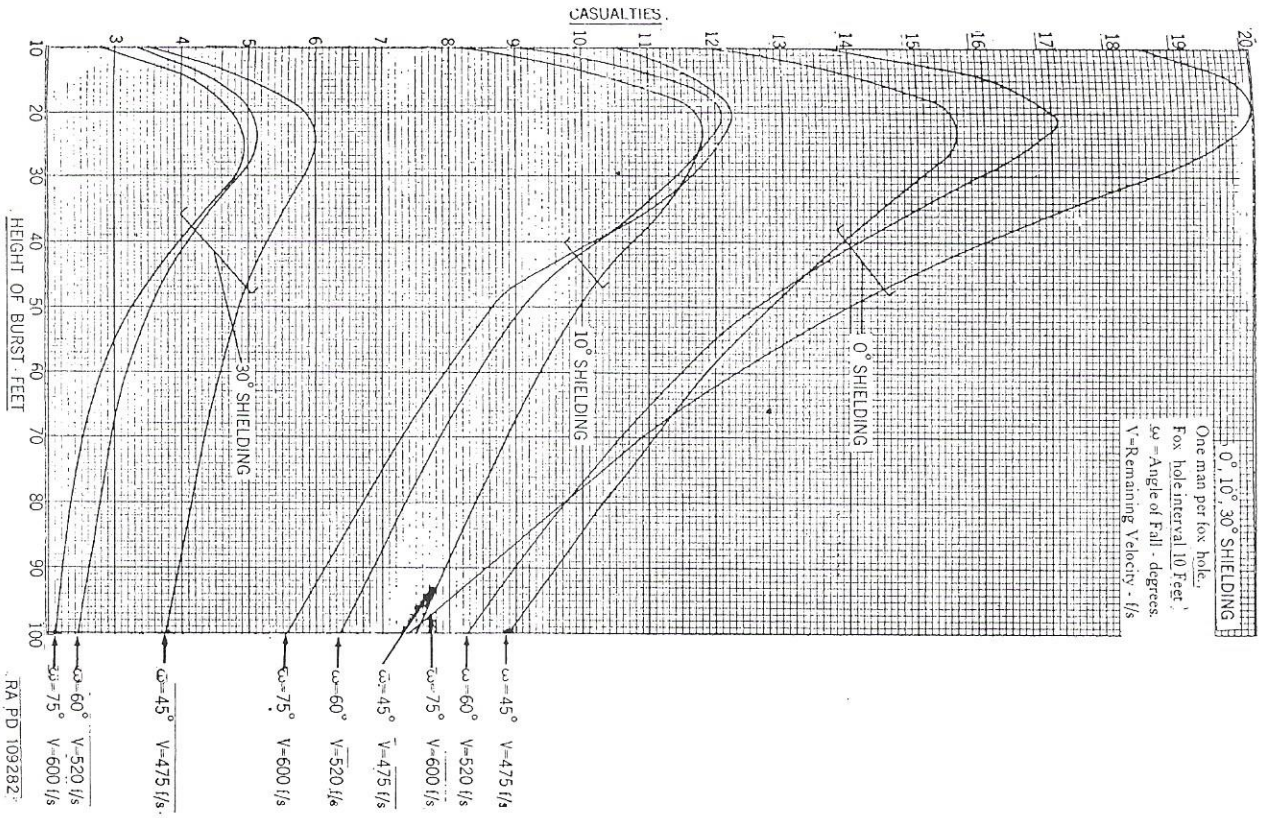


Figure 34. Casualties vs height of burst – 20-lb fragmentation bomb, AN-M41 or AN-M41A1.

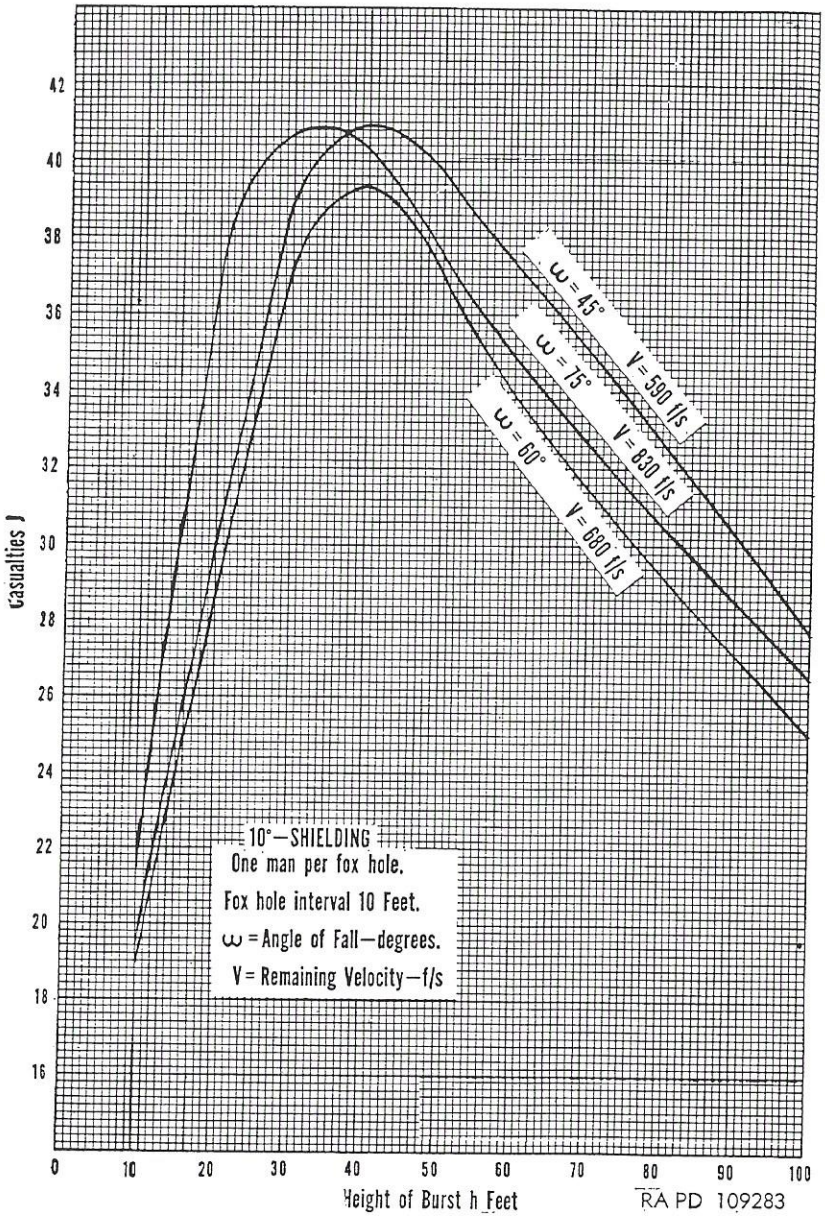


Figure 55. Casualties vs height of burst – 90-lb fragmentation bomb, M82.

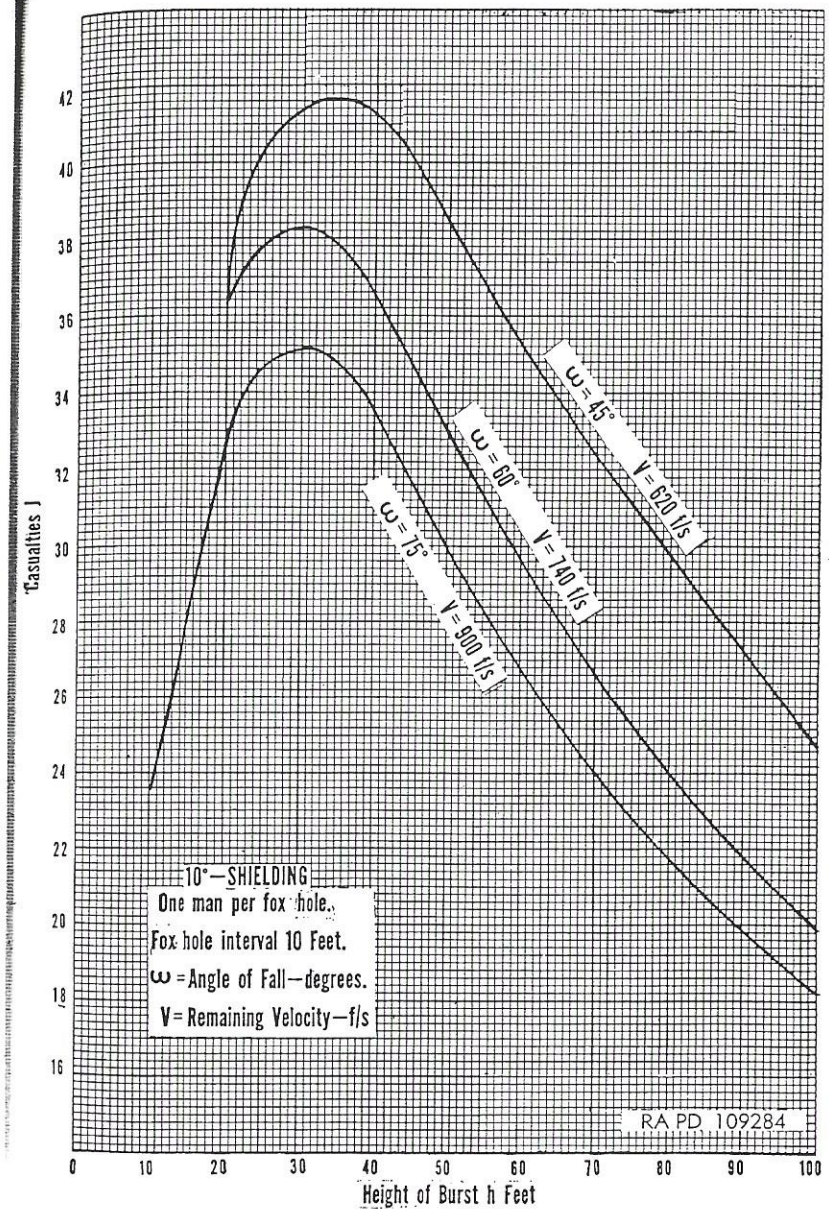


Figure 56. Casualties vs height of burst – 100-lb GP bomb, AN-M30 or AN-M30A1.

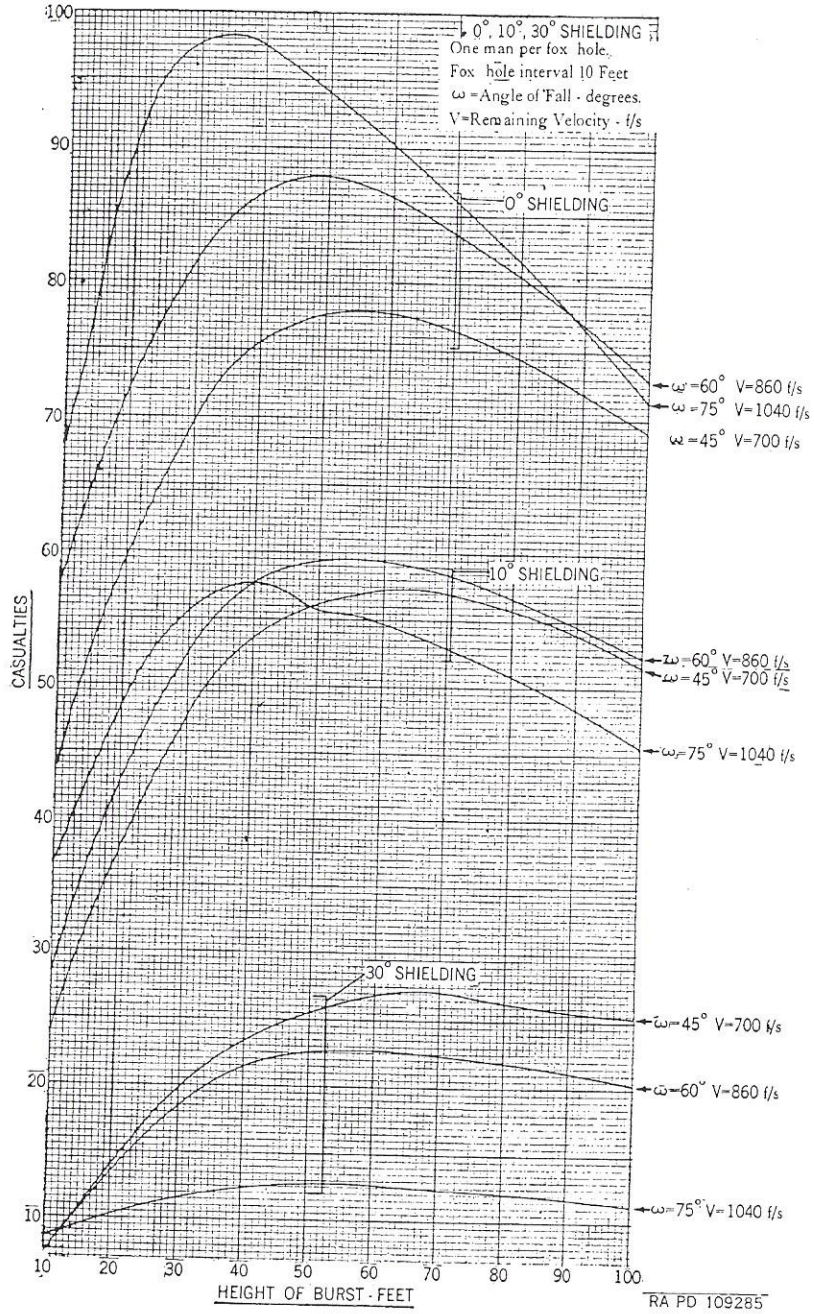


Figure 57. Casualties vs height of burst – 260-lb fragmentation bomb, AN-M81.

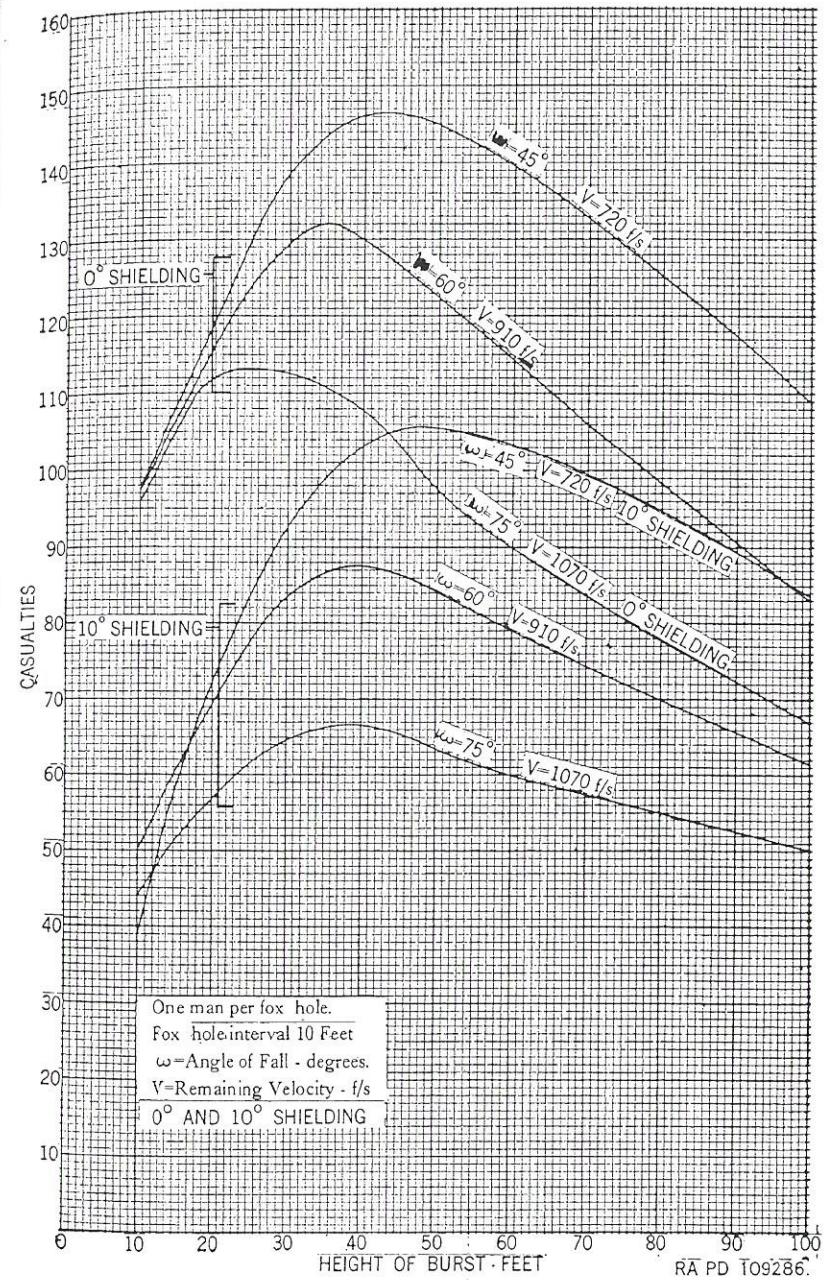


Figure 58. Casualties vs height of burst – 500-lb GP bomb, AN-M64 or AN-M64A1.

Section VI. EARTH PENETRATION: CRATER FORMATION AND EARTH SHOCK

30. General

Information on the travel of bombs in earth, on the depths reached with various fuze settings, and on the size and types of craters produced in different soils is presented in figures 59 and 60 and tables XV to XXI. The underground trajectory may be of importance in considering the attack on fortifications. (See sec. VIII, ch. 2.) Accidental and irreproducible factors such as the type of earth, differences in the constitution of the earth at the point of impact, stones, etc., have a large influence on the behavior of penetrating bombs.

31. Shape of the Underground Trajectories

The underground trajectories of bombs are generally J-shaped (fig. 59). A bomb travels straight as long as its yaw remains small, but swerves after its instability has resulted in a considerable yaw. Swerving generally occurs in such a direction to bring the bomb nearer to the ground surface, but it is quite erratic. Bombs frequently swerve to the right or left of their initial trajectory, resulting in considerable lateral offset, sometimes even in a backward direction with respect to the motion of a bombing plane. It is reported that American bombs swerve to a considerably lesser extent than similar British or German bombs, that is, the J-shape of their path is less pronounced.

32. Fuze Delay

The times of operation of the nose fuze with instantaneous setting and any of the standard tail fuzes with a nondelay detonator have been estimated to be as follows :

Instantaneous nose.....0.0005 second.

Nondelay tail.....0.002 to 0.003 second (depending on the size of the bomb).

The time limits for delay elements of the American tail fuzes, with Primer-Detonator M14, are set by acceptance tests as follows:

0.01 second nominal delay: 0.007 to 0.014 second.

0.025 second nominal delay: 0.018 to 0.032 second.

0.1 second nominal delay: 0.10 to 0.15 second.

Variations within these limits may affect the depth of the burst and hence the crater size to a considerable extent.

33. Quality of the Soil

Different soils may be arranged in a rough scale with respect to their resistance to bomb penetration and detonation. Dry sand is extremely high in resistance because it does not easily transmit and distribute the action of the bomb over a wide region, and because its successive layers have to be crushed with considerable waste of energy. Conversely, wet clay is extremely low in resistance. The water content tends to distribute the effects of penetration and detonation over wide ranges, so that wet clay can more easily "give in" to a bomb without being crushed. In general, the greater the water content and plasticity the soil may have, the less resistance it offers to penetration and to the formation of large craters. Data for three types of soil are given in the accompanying tables. These soils have been labeled as soft, corresponding to a fairly wet clay; medium, corresponding to a sandy clay loam or to soft chalk; and hard, corresponding to sand or gravel or mixtures thereof. Some degree of interpolation between these types of soils is possible. It appears that the maximum crater diameter does not depend on the quality of the soil to the same extent as does the depth of penetration.

34. Displacement and Depth Penetrated

Displacement and depth penetrated are illustrated in figure 59. They are measured from the center of the hole of entry at ground level to the center of gravity of the bomb at the time of detonation. Displacement is measured horizontally, in the direction of plane travel; depth is measured perpendicular to the surface. The negative values in the table for quick fuzing indicate that the center of gravity of the bomb does not reach ground level before detonation. While figure 59 is scaled for the 500-pound GP bomb, trajectory shapes are essentially similar and figures from the tables may be applied to the illustration to obtain an accurate picture for the bombs.

35. Crater Measurements and Type

a. Measurements. Crater diameter, apparent depth, and actual depth are illustrated in figure 60. These representations are typical and not specific; they are given only to illustrate the application of the data given in the tables following.

b. Volume for Refill. The amount of material that must be trucked in to refill a bomb crater affects considerably the amount of effort that must be spent in repairing it. This amount of material excludes the loose material that is already available in the bottom or on the lip of the crater. Also, this amount depends not only on the apparent volume of the crater, but also on the amount of soil crushed, loosened, or displaced

in the crater bottom. Crude estimates of the volume of loose soil that must be trucked in for repair are shown in the accompanying tables. Figures given are based on the assumption that all the available and trucked-in soil must be packed hard. It is estimated also that the manpower requirement for repair may run at about 1½ man-hours per cubic yard of material needed.

c. TYPES. A series of crater types is illustrated in figure 60 to serve as a guide in interpretation of the crater type data given in tables XV to XXI.

36. Bombing from Minimum Altitude

Bombs generally ricochet when dropped on level or gently sloping soil from planes flying at minimum altitude. Such bombs will penetrate steep embankments. If, for example, the releasing plane flies at nearly 400 miles per hour, and the embankment has a 45 degree inclination, the penetration path followed will not differ much from that of a bomb dropped from 5,000 feet on level ground. Less penetration will be achieved if the plane is slower or the embankment is not so steep.

37. Earth Shock Effect

A violent shock is propagated earthquake-like through the earth from the point of a bomb explosion. The demolition of buildings by earth shock is somewhat unpredictable, since it appears to depend, among other things, on whether the building can vibrate in phase with the shock waves from the detonated bomb. Demolition does not appear to extend to buildings which are at a greater distance from the point of burst than the maximum crater diameter produced by the bomb. Damage to fixed gun emplacements by the bomb action tilting them effectively seems to be confined to a distance of about ¾ the maximum crater diameter. Damage to ceramic service pipes (of earthenware, brick, or tile) seems to extend to pipes whose closest approach to the point of detonation is equal to or slightly greater than the maximum crater diameter. Damage to cast iron pipes is likely to occur up to distances from the point of burst of about 0.6 of the maximum crater diameter. Any trench or duct tends to absorb a ground shock, even though its walls may be damaged. In particular, service pipes laid in ducts are effectively protected, unless included in the crater itself. Adjacent structures or earthworks will shift the center of the crater from the point of detonation. The presence of a trench relieves the earth pressure, so that craters are shifted in that direction. On the other hand craters are shifted away from embankments or strong structures that withstand the earth shock. The effect or earth shock on the underground portions of fortifications is discussed in section VIII, chapter 2.

38. Underfooting of Columns and Stanchions

Cratering action of bombs may be exploited to remove the ground support from columns or stanchions in industrial structures. It is estimated that this form of attack will be successful whenever the foot of a structural element falls within the crater limits. Attack of structures by cratering seems to be particularly valuable against the strongest type of factory buildings, namely those with gantry cranes. These structures may be strong enough to withstand the removal of a single column. Consequently, bombs large enough to contain two columns in one crater are recommended.

39. Orientation of a Detonating Bomb

The orientation of a bomb detonating underground and the thickness of the bomb casing do not seem to have much influence on the resulting effects. Only the nature and amount of charge and the position of its center have to be considered.

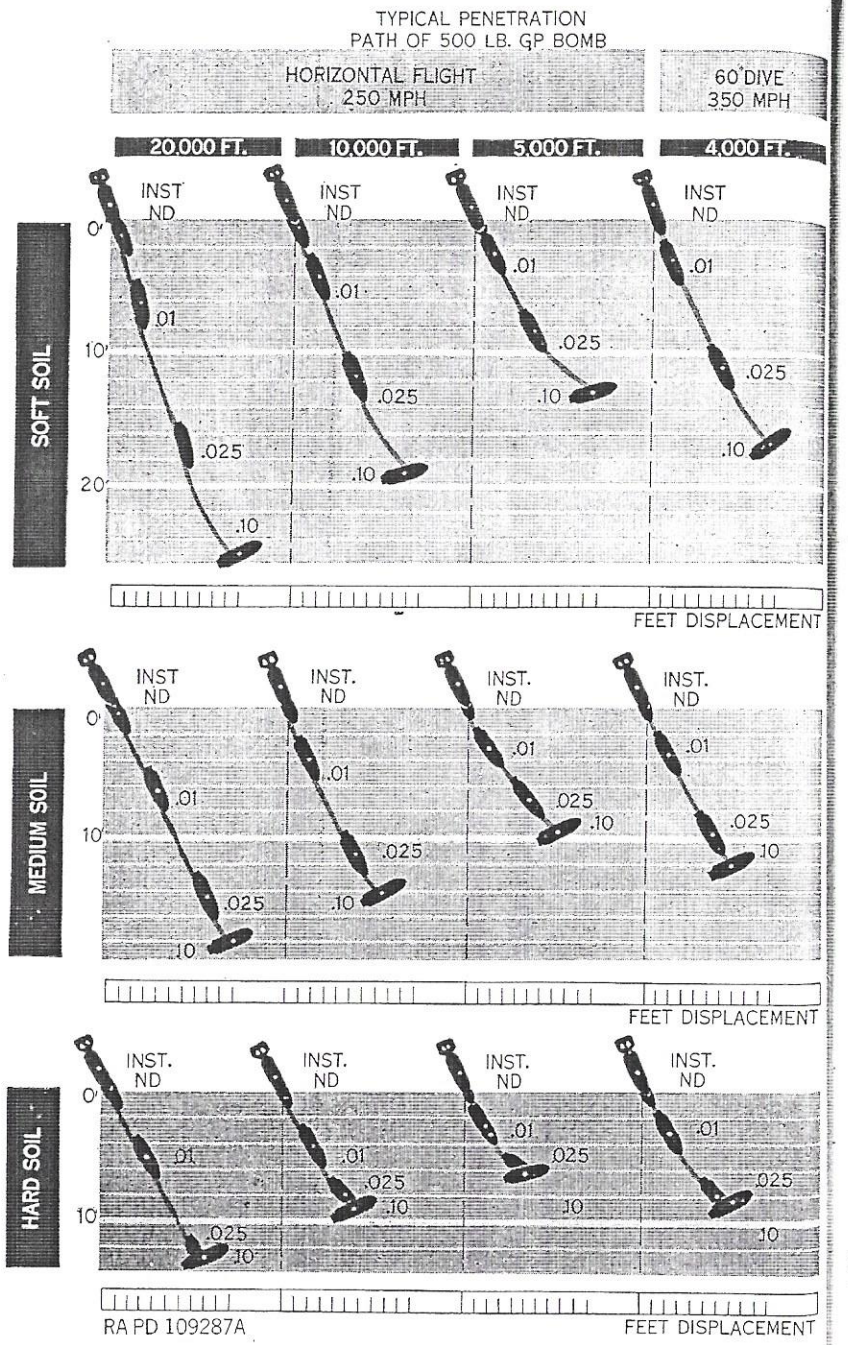


Figure 59. Typical penetration paths of 500-lb GP bomb.

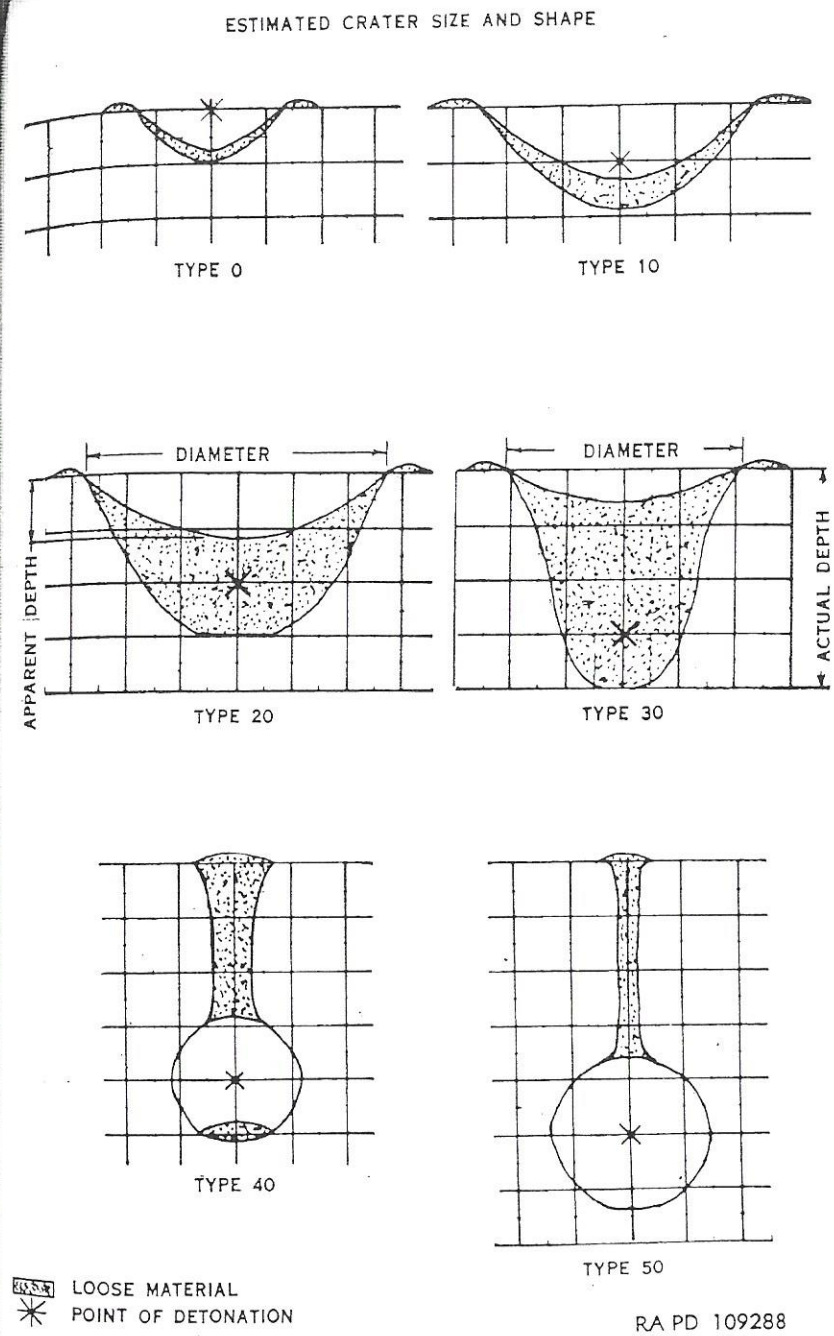


Figure 60.—Crater types—estimated crater size and shape.

Table XV. Earth Penetration and Crater Formation—GP Bombs Released at 20,000 Feet and 250 Miles per Hour—Level Flight

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
100 lb. GP AN-M30A1, AN-M30	0.0005 (inst.)	Soft	−0.17	−0.72	10.0	2.8	3.1	—	−1.7
		Medium	−0.17	−0.72	7.9	3.0	3.4	—	−1.9
		Hard	−0.17	−0.72	6.0	1.6	1.8	—	−2.4
	0.002 (nondelay)	Soft	0.11	0.50	13	3.9	4.8	12	1.2
		Medium	0.11	0.48	11	3.4	3.9	4	1.3
		Hard	0.10	0.46	9.9	2.7	3.3	2	1.5
	0.01	Soft	1.5	6.1	22	6.9	12	46	14
		Medium	1.6	5.6	20	5.1	9.3	30	15
		Hard	1.4	5.1	16	2.6	8	15	17
	0.025	Soft	3.5	12.0	21	2.8	14	24	28
		Medium	3.6	9.6	19	3.0	14	18	25
		Hard	2.9	6.8	16	3.0	10	14	23
	0.10	Soft	4.9	14.0	16	1.3	19	18	32
		Medium	3.8	9.6	19	3.0	14	18	25
		Hard	2.9	6.8	16	3.0	9.9	14	23
250 lb. GP AN-M57A1, AN-M57	0.0005 (inst.)	Soft	−0.25	−1.0	13	4	3.5	—	−1.8
		Medium	−0.25	−1.0	11	3	3.2	—	−2.0
		Hard	−0.24	− .97	8	2.4	2.2	—	−2.4
	0.0023 (nondelay)	Soft	0.15	0.59	17	5.7	5.1	19	1.0
		Medium	0.14	0.58	15	4.5	4.0	13	1.2
		Hard	0.14	0.55	12	4.1	3.5	10	1.4
	0.01	Soft	1.7	6.7	29	7.8	12	100	12
		Medium	1.6	6.3	25	6.9	11	66	13
		Hard	1.5	6.0	21	5.4	10	35	15
	0.025	Soft	3.8	15	28	4.3	21	60	26
		Medium	4.2	13	25	3.7	18	40	26
		Hard	4.1	9.1	21	2.3	13	33	23
	0.10	Soft	7.1	19	20	1.1	25	40	33
		Medium	5.4	14	24	3.2	19	37	27
		Hard	4.1	9.1	21	2.3	13	32	23
500 lb. GP AN-M64A1, AN-M64, AN-M43	0.0005 (inst.)	Soft	−0.38	−1.3	16	4.4	5.1	—	−1.8
		Medium	−0.38	−1.3	14	3.2	4.2	—	−2.0
		Hard	−0.38	−1.3	10	2.6	3.1	—	−2.6
	0.0025 (nondelay)	Soft	0.14	0.50	24	9.3	10	48	0.68
		Medium	0.14	0.49	19	5.4	6.4	33	0.76
		Hard	0.13	0.46	15	4.5	5.1	19	0.90
	0.01	Soft	2.0	6.9	35	9.8	14	200	9.4
		Medium	1.9	6.6	31	8.6	12	140	10.0
		Hard	1.8	6.2	26	7.1	11	72	12.0

Table XV. Earth Penetration and Crater Formation—GP Bombs Released at 20,000 Feet and 250 Miles per Hour—Level Flight—Continued

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
500 lb. GP AN-M64A1, AN-M64, AN-M43	0.025	Soft	4.9	17	38	7.0	24	200	23
		Medium	4.8	15	33	6.1	21	120	24
		Hard	5.1	12	26	4.6	17	61	24
	0.10	Soft	10.3	25	22	3.5	33	81	35.0
		Medium	7.7	18	30	3.8	25	100	28.0
		Hard	5.8	13	26	4.3	18	48	25.0
1,000 lb. GP AN-M65A1, AN-M65, AN-M44	0.0005 (inst.)	Soft	−0.46	−1.6	20	5.8	6.4	—	−1.7
		Medium	−0.46	−1.6	18	4.9	5.7	—	−2.0
		Hard	−0.46	−1.6	11	3.6	3.9	—	−2.5
	0.0027 (nondelay)	Soft	0.14	0.49	27	7.9	8.8	100	0.53
		Medium	0.14	0.48	24	6.9	8.1	64	0.59
		Hard	0.13	0.46	19	6.5	5.5	34	0.71
	0.01	Soft	2.0	7.0	42	12	16	360	7.5
		Medium	1.9	6.7	37	10	15	250	8.3
		Hard	1.8	6.3	31	8.8	12	140	9.7
	0.025	Soft	5.1	18	50	11	27	450	19
		Medium	4.3	15	43	10	23	300	18
		Hard	5.2	13	35	7.7	19	150	20
	0.10	Soft	11.2	28	40	4.2	42	200	30
		Medium	8.4	20	42	6.9	28	220	24
		Hard	6.3	14	35	7.1	20	150	21
2,000 lb. GP AN-M66A2, AN-M66A1, AN-M66, AN-M34	0.0005 (inst.)	Soft	−0.63	−2.2	26	7.2	8.2	—	−2.0
		Medium	−0.63	−2.2	21	6.3	6.9	—	−2.2
		Hard	−0.63	−2.2	16	4.1	4.9	—	−2.7
	0.0030 (nondelay)	Soft	0.066	0.23	32	9.4	10	160	0.19
		Medium	0.062	0.22	29	8.2	9.3	100	0.22
		Hard	0.054	0.19	22	6.5	7.4	55	0.23
	0.01	Soft	1.9	6.6	48	13	18	600	5.6
		Medium	1.8	6.4	43	13	16	420	6.3
		Hard	1.8	6.2	37	11	14	240	7.6
	0.025	Soft	5.3	18	61	15	30	900	16
		Medium	4.9	17	54	13	28	600	18
		Hard	4.9	15	44	9.8	23	300	19
	0.10	Soft	15.0	38	42	15	51	350	33
		Medium	12.0	27	50	17	38	320	27
		Hard	8.7	19	47	8	27	290	23

Table XVI. Earth Penetration and Crater Formation—GP Bombs Released at 10,000 Feet and 250 Miles per Hour—Level Flight

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
100 lb. GP AN-M30A1, AN-M30	0.0005 (inst.)	Soft	−0.29	−0.76	9.6	2.7	3.0	—	−1.7
		Medium	−0.29	−0.76	8.2	2.3	2.5	—	−2.0
		Hard	−0.29	−0.76	6.0	2.0	1.8	—	−2.5
	0.002 (nondelay)	Soft	0.087	0.23	12	3.7	4.1	9	.53
		Medium	0.076	0.20	11	3.2	3.6	6	.53
		Hard	0.070	0.18	8.7	2.6	2.8	3	.60
	0.01	Soft	1.8	4.7	21	6.4	9.6	43	11.0
		Medium	1.7	4.4	20	5.2	7.9	29	12.0
		Hard	1.6	3.9	15	4.1	6.8	15	13.0
	0.025	Soft	4.4	9.9	23	2.3	14	42	23.0
		Medium	3.8	7.3	21	4.5	11	30	19.0
		Hard	3.2	5.1	16	3.9	8.1	15	17.0
	0.10	Soft	5.8	11	22	3.7	15	30	25.0
		Medium	4.3	7.6	20	4.3	12	30	20.0
		Hard	3.2	5.1	16	3.9	8.1	15	17.0
250 lb. GP AN-M57A1, AN-M57	0.0005 (inst.)	Soft	−0.41	−1.0	12	3.5	4.0	—	−1.8
		Medium	−0.41	−1.0	11	3.0	3.4	—	−2.0
		Hard	−0.41	−1.0	8.0	2.2	2.4	—	−2.5
	0.0023 (nondelay)	Soft	0.087	0.22	16	4.7	5.3	20	0.38
		Medium	0.074	0.18	14	4.0	4.5	13	0.36
		Hard	0.075	0.18	11	3.2	3.6	7	0.45
	0.01	Soft	2.0	5.0	27	5.9	10	91	8.7
		Medium	1.9	4.7	24	6.6	9.4	61	9.4
		Hard	1.8	4.4	20	5.5	8.2	33	11.0
	0.025	Soft	4.8	12	31	6.3	17	100	21.0
		Medium	4.9	9.6	26	6.0	14	68	19.0
		Hard	4.2	6.8	21	5.2	11	35	17.0
	0.01	Soft	8.1	15	29	4.3	20	65	26
		Medium	6.1	10	27	5.4	15	68	21
		Hard	4.6	7	21	5.0	11	35	18
500 lb. GP AN-M64A1, AN-M64, AN-M43	0.0005 (inst.)	Soft	−0.58	−1.4	16	4.4	5.1	—	−1.90
		Medium	−0.58	−1.4	14	3.8	5.0	—	−2.20
		Hard	−0.58	−1.4	9.7	2.8	3.1	—	−2.70
	0.0025 (nondelay)	Soft	0.038	0.089	20	6.0	6.7	40	0.12
		Medium	0.024	0.057	18	5.1	5.8	26	0.089
		Hard	0.016	0.039	14	4.0	4.6	13	0.076
	0.01	Soft	2.1	5.0	33	9.2	12.0	170	6.8
		Medium	2.0	4.8	29	8.3	11.0	118	7.5
		Hard	1.9	4.5	24	6.6	8.7	64	8.8

Table XVI. Earth Penetration and Crater Formation—GP Bombs Released at 10,000 Feet and 250 Miles per Hour—Level Flight—Continued

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
500 lb. GP AN-M64A1, AN-M64, AN-M43	0.025	Soft	5.5	13.0	39	9.2	20	220	18.0
		Medium	5.2	11.4	34	8.1	18	150	18.0
		Hard	5.4	8.8	27	6.6	14	74	17.0
	0.10	Soft	11.0	19.4	36	5.0	27	130	26
		Medium	8.2	13.6	34	6.9	20	140	21
		Hard	6.1	9.2	27	6.4	19	74	18
1,000 lb. GP AN-M65A1, AN-M65, AN-M44	0.0005 (inst.)	Soft	−0.69	−1.6	21	6.5	5.7	—	−1.7
		Medium	−0.69	−1.6	18	6.3	5.5	—	−2.0
		Hard	−0.69	−1.6	13	3.9	3.6	—	−2.5
	0.0027 (nondelay)	Soft	−0.0042	−0.010	25	8.4	7.4	—	−0.011
		Medium	−0.0105	−0.0248	10	7.3	6.5	—	−0.031
		Hard	−0.0187	−0.0442	18	5.2	5.8	—	−0.068
	0.01	Soft	2.2	5.2	38	11	14	300	5.6
		Medium	2.1	5.0	34	9.9	13	210	6.2
		Hard	2.0	4.7	29	8.4	11	120	7.2
	0.025	Soft	5.6	13.2	49	13	22	450	14.0
		Medium	5.2	11.8	42	11	19	300	15.0
		Hard	5.4	9.3	34	8.8	16	150	14.0
	0.10	Soft	11.9	20.9	49	9.3	30	420	22
		Medium	8.8	14.6	43	10	23	300	18
		Hard	6.6	9.9	34	8.8	16	150	15
2,000 lb. GP AN-M66A2, AN-M66A1, AN-M66, AN-M34	0.0005 (inst.)	Soft	−0.97	−2.2	26	7.6	8.4	—	−1.9
		Medium	−0.97	−2.2	21	6.6	6.0	—	−2.2
		Hard	−0.97	−2.2	16	4.5	4.8	—	−2.7
	0.0030 (nondelay)	Soft	−0.15	0.33	22	7.0	5.8	—	−2.8
		Medium	−0.15	0.34	17	4.8	5.1	—	−3.3
		Hard	−0.16	0.36	11	2.8	2.8	—	−4.4
	0.01	Soft	2.0	4.6	44	13	15	460	3.9
		Medium	2.0	4.4	39	12	14	300	4.3
		Hard	1.9	4.2	33	9.8	12	190	5.1
	0.025	Soft	6.1	14	58	16	25	850	12
		Medium	5.7	13	52	14	22	560	13
		Hard	5.0	10	41	11	18	300	13
	0.10	Soft	17	28	61	9.9	40	620	24
		Medium	12	20	55	12.0	30	580	20
		Hard	9.3	14	43	11.0	22	300	17

Table XVII. Earth Penetration and Crater Formation—GP Bombs Released at 5,000 Feet and 250 Miles per Hour—Level Flight

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
100 lb. GP AN-M30A1, AN-M30	0.0005 (inst.)	Soft	−0.45	−0.76	9.6	2.7	3.0	—	−1.7
		Medium	−0.45	−0.76	8.2	2.3	2.5	—	−2.0
		Hard	−0.45	−0.76	6.0	1.6	1.8	—	−2.5
	0.002 (nondelay)	Soft	−0.021	−0.035	12	3.5	3.9	—	−0.08
		Medium	−0.029	−0.048	10	3.0	3.3	—	−0.13
		Hard	−0.036	−0.060	8.1	2.4	2.7	—	−0.20
	0.01	Soft	2.0	3.3	20	5.6	7.4	37	7.6
		Medium	1.8	3.1	17	4.9	6.6	25	8.2
		Hard	1.8	2.6	15	4.1	6.8	15	13.0
	0.025	Soft	4.9	7.0	23	5.6	11	46	16
		Medium	4.5	5.2	20	5.2	8.9	30	14
		Hard	3.5	3.5	15	4.2	6.3	14	12
	0.10	Soft	6.2	7.6	24	5.5	12	46	18
		Medium	4.6	5.2	20	5.2	8.9	30	14
		Hard	3.5	3.5	15	4.2	6.3	14	12
250 lb. GP AN-M57A1, AN-M57	0.0005 (inst.)	Soft	−0.62	−0.99	12	3.5	4.0	—	−1.7
		Medium	−0.62	−0.99	11	3.0	3.4	—	−2.0
		Hard	−0.62	−0.99	8.0	2.2	2.4	—	−2.5
	0.0023 (nondelay)	Soft	−0.049	−0.079	15	4.5	5.1	—	−0.14
		Medium	−0.055	−0.088	13	3.8	4.3	—	−0.17
		Hard	−0.063	−0.012	11	3.2	3.6	—	−0.25
	0.01	Soft	2.2	3.4	24	6.9	8.6	71	5.9
		Medium	2.0	3.3	21	6.2	7.9	51	6.6
		Hard	1.9	3.0	18	5.2	7.2	28	7.5
	0.025	Soft	5.2	8.5	30	7.7	14	100	15
		Medium	5.3	6.7	25	6.8	11	67	14
		Hard	4.7	4.7	20	5.4	8.3	34	12
	0.10	Soft	8.6	10	30	7.2	16	100	18
		Medium	6.5	7.1	26	6.7	12	68	14
		Hard	4.8	4.8	20	5.5	8.8	32	12
00 lb. GP AN-M64A1, AN-M64, AN-M43	0.0005 (inst.)	Soft	−0.83	−1.3	16	3.7	4.4	—	−1.8
		Medium	−0.83	−1.3	14	4.2	3.2	—	−2.0
		Hard	−0.83	−1.3	10	3.1	2.6	—	−2.6
	0.0025 (nondelay)	Soft	−0.18	−0.29	20	6.0	6.7	—	−0.39
		Medium	−0.18	−0.30	17	4.8	5.4	—	−0.47
		Hard	−0.20	−0.31	13	3.6	4.1	—	−0.60
	0.01	Soft	2.1	3.3	28	8.4	10	130	4.5
		Medium	2.0	3.2	26	7.6	12	92	5.0
		Hard	1.8	2.9	21	6.1	7.6	50	5.7

Table XVII. Earth Penetration and Crater Formation—GP Bombs Released at 5,000 Feet and 250 Miles per Hour—Level Flight—Continued

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
500 lb. GP AN-M64A1, AN-M64, AN-M43	0.025	Soft	5.7	9.1	37	10	16	220	12
		Medium	5.1	8.2	33	8.9	14	150	12
		Hard	5.7	6.0	26	7.0	11	71	12
	0.10	Soft	11.2	13.5	39	8.9	21	220	18
		Medium	8.3	9.3	34	8.6	15	150	14
		Hard	6.1	6.2	26	7.1	11	72	12
1,000 lb. GP AN-M65A1, AN-M65, AN-M44	0.0005 (inst.)	Soft	−1.0	−1.6	21	6.5	5.7	—	−1.7
		Medium	−1.0	−1.6	18	6.3	5.5	—	−2.0
		Hard	−1.0	−1.6	13	3.9	3.6	—	−2.5
	0.0027 (nondelay)	Soft	−0.25	−0.40	24	7.0	7.9	—	−0.43
		Medium	−0.26	−0.41	21	6.0	6.9	—	−0.51
		Hard	−0.26	−0.42	16	4.9	5.5	—	−0.65
	0.01	Soft	2.0	3.2	34	10	12	230	3.4
		Medium	1.9	3.0	30	8.9	10	150	3.7
		Hard	1.9	2.8	25	7.2	8.8	85	4.3
	0.025	Soft	5.8	9.2	45	13	18	400	9.9
		Medium	5.6	8.4	40	11	16	280	10.0
		Hard	5.4	6.2	32	8.8	12	140	9.5
	0.10	Soft	12.0	14.5	48	13	23	450	16
		Medium	8.9	10.0	41	11	18	300	12
		Hard	6.6	6.6	32	8.8	13	140	10
2,000 lb. GP AN-M66A2, AN-M66A1, AN-M66, AN-M34	0.0005 (inst.)	Soft	−1.3	−2.1	26	7.6	8.4	—	−1.8
		Medium	−1.3	−2.1	21	6.6	6.0	—	−2.1
		Hard	−1.3	−2.1	16	4.5	4.8	—	−2.6
	0.0030 (nondelay)	Soft	−0.46	−0.74	29	9.9	8.8	—	−0.63
		Medium	−0.47	−0.75	25	7.4	8.2	—	−0.73
		Hard	−0.49	−0.78	20	5.7	6.5	—	−0.96
	0.01	Soft	1.8	2.8	40	12	12	350	2.4
		Medium	1.7	2.7	35	10	12	230	2.6
		Hard	1.6	2.6	29	8.6	10	140	3.2
	0.025	Soft	6.0	9.5	53	15	20	740	8.1
		Medium	5.5	8.8	47	13	17	500	8.6
		Hard	5.5	5.5	34	10	13	300	6.7
	0.10	Soft	17	20	62	15	32	900	17
		Medium	12	14	52	14	24	570	14
		Hard	9.1	9.2	40	11	17	290	13

Table XVIII. Earth Penetration and Crater Formation—GP Bombs Released at 4,000 Feet and 350 Miles per Hour—60° Dive

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
100 lb. GP AN-M30A1, AN-M30	0.0005 (inst.)	Soft	−0.29	−0.79	10	2.7	3.0	—	−1.8
		Medium	−0.29	−0.79	7.9	2.3	2.6	—	−2.1
		Hard	−0.29	−0.80	5.7	1.6	1.8	—	−2.7
	0.002 (nondelay)	Soft	0.03	0.09	12	3.5	4.0	8.2	0.21
		Medium	0.03	0.08	10	3.0	3.4	5.4	0.21
		Hard	0.02	0.07	8	2.4	2.7	2.7	0.23
	0.01	Soft	1.6	4.5	21	5.9	8.7	42	10
		Medium	1.4	4.0	18	5.1	7.6	28	11
		Hard	1.5	3.5	15	4.2	6.3	14	12
	0.025	Soft	3.8	9.0	23	4.8	13	46	21
		Medium	3.8	6.8	20	4.6	11	30	18
		Hard	3.0	4.7	16	4.0	7.6	15	16
	0.10	Soft	5.2	10	23	4.2	14	41	23
		Medium	3.9	6.9	20	4.6	11	30	18
		Hard	3.0	4.7	16	4.0	7.6	15	16
250 lb. GP AN-M57A1, AN-M57	0.0005 (inst.)	Soft	−0.29	−0.78	13	3.9	4.3	—	1.4
		Medium	−0.29	−0.78	11	3.7	3.1	—	1.6
		Hard	−0.29	−0.78	8.6	2.4	2.7	—	2.0
	0.0023 (nondelay)	Soft	0.12	0.32	16	4.9	5.4	22	0.56
		Medium	0.12	0.31	14	4.2	4.8	15	0.62
		Hard	0.11	0.30	12	3.4	3.8	8.5	0.75
	0.01	Soft	1.7	4.6	26	7.4	10	86	8.0
		Medium	1.6	4.3	23	6.4	8.9	59	8.7
		Hard	1.6	3.9	19	5.4	7.6	32	9.8
	0.025	Soft	4.1	11	30	7.0	16	105	18
		Medium	4.3	8.6	26	6.4	13	69	17
		Hard	4.0	6.2	21	5.3	10	35	16
	0.10	Soft	7.0	13	30	5.5	19	98	23
		Medium	5.3	9.2	26	6.0	14	68	18
		Hard	4.0	6.2	21	5.3	10	35	16
500 lb. GP AN-M64A1, AN-M64, AN-M43	0.0005 (inst.)	Soft	−0.55	−1.4	16	4.6	4.9	—	−1.9
		Medium	−0.55	−1.4	13	4.4	3.8	—	−2.2
		Hard	−0.55	−1.4	9.9	3.1	2.8	—	−2.7
	0.0025 (nondelay)	Soft	−0.07	−0.18	20	5.1	5.8	—	−0.24
		Medium	−0.07	−0.19	17	4.7	5.4	—	−0.30
		Hard	−0.08	−0.20	13	4.5	3.8	—	−0.39
	0.01	Soft	1.6	4.2	30	8.1	11	150	5.7
		Medium	1.5	4.0	27	7.8	9.9	100	6.2
		Hard	1.4	3.7	22	6.6	8.4	58	7.2

Table XVIII. Earth Penetration and Crater Formation—GP Bombs Released at 4,000 Feet and 350 Miles per Hour—60° Dive—Continued

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
500 lb. GP AN-M64A1, AN-M64, AN-M43 —Continued	0.025	Soft	4.3	11	38	9.9	18	220	15
		Medium	4.2	9.8	33	8.6	16	150	15
		Hard	4.8	7.9	27	6.9	13	74	16
	0.10	Soft	9.1	17	39	7.0	24	200	23
		Medium	6.9	12	34	7.7	18	150	18
		Hard	5.2	8	27	6.9	13	74	16
1,000 lb. GP AN-M65A1, AN-M65, AN-M44	0.0005 (inst.)	Soft	−0.65	−1.7	20	5.8	6.5	—	−1.8
		Medium	−0.65	−1.7	17	4.8	5.6	—	−2.1
		Hard	−0.65	−1.7	13	3.5	4.0	—	−2.6
	0.0027 (nondelay)	Soft	−0.11	−0.29	25	6.4	7.2	88	0.3
		Medium	−0.12	−0.31	21	6.1	6.9	58	0.3
		Hard	−0.12	−0.32	23	11.0	12.0	32	0.4
	0.01	Soft	1.5	4.0	35	10	13	250	4.3
		Medium	1.5	3.8	32	9.3	11	170	4.7
		Hard	1.4	3.6	27	7.8	9.8	100	5.5
	0.025	Soft	4.3	13.2	48	13	22	450	14
		Medium	4.1	10	40	11	18	290	12
		Hard	4.4	8.0	33	9.0	14	150	12
	0.10	Soft	9.8	18	52	11	27	450	20
		Medium	7.4	13	42	11	21	300	16
		Hard	5.5	8.6	33	9	15	150	13
2,000 lb. GP AN-M66A2, AN-M66A1, AN-M66, AN-M34	0.0005 (inst.)	Soft	−0.83	−2.3	26	7.2	8.2	—	−2.0
		Medium	−0.84	−2.3	21	6.0	6.6	—	−2.2
		Hard	−0.84	−2.3	16	4.5	4.9	—	−2.8
	0.0030 (nondelay)	Soft	−0.25	−0.68	29	8.8	9.9	—	−0.58
		Medium	−0.25	−0.69	26	7.3	8.2	—	−0.68
		Hard	−0.26	−0.71	20	5.9	6.7	—	−0.87
	0.01	Soft	1.3	3.6	41	12	15	400	3.1
		Medium	1.3	3.5	37	11	13	270	3.4
		Hard	1.2	3.3	31	9	11	160	4.0
	0.025	Soft	4.2	12	56	16	22	800	9.8
		Medium	3.9	11	50	14	20	540	10
		Hard	4.1	9.3	40	11	17	290	11
	0.10	Soft	13	25	63	12	37	880	21
		Medium	9.7	17	54	13	28	580	17
		Hard	7.3	12	42	11	20	300	14

Table XIX. Earth Penetration and Crater Formation—SAP Bombs

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
	Altitude of release, 20,000 ft.—airspeed, 250 mph—level flight								
500 lb. SAP AN-M58A2, AN-M58A1, AN-M58	0.0005 (inst.)	Soft	−0.38	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.38	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.38	−1.4	7.3	1.9	1.8	—	−3.3
	0.0027 (nondelay)	Soft	0.18	0.65	17	4.9	4.3	44	1.0
		Medium	0.17	0.64	15	4.9	4.4	25	1.2
		Hard	0.16	0.61	12	4.0	3.5	14	1.4
	0.01	Soft	1.9	7.0	31	8.5	13	120	11
		Medium	1.8	6.8	27	7.4	12	83	13
		Hard	1.7	6.5	22	5.8	11	44	15
	0.025	Soft	4.8	18.0	28	3.2	24	60	29
		Medium	4.4	16	22	2.1	22	37	31
		Hard	4.9	14	16	1.3	18	18	32
	0.10	Soft	12	31	—	—	39	30	51
		Medium	9	22	4.8	—	28	20	41
		Hard	6.8	15	12.0	—	19	16	35
1,000 lb. SAP AN-M59A1, AN-M59	0.0005 (inst.)	Soft	−0.51	−1.8	19	4.6	5.0	—	−2.3
		Medium	−0.51	−1.8	13	3.0	3.4	—	−2.7
		Hard	−0.51	−1.8	9.2	2.4	2.9	—	−3.3
	0.0030 (nondelay)	Soft	0.20	0.68	22	6.7	7.4	60	0.88
		Medium	0.19	0.66	20	6.6	5.9	43	0.98
		Hard	0.18	0.63	16	4.9	5.4	24	1.20
	0.01	Soft	2.1	7.2	37	10	14	230	9.3
		Medium	2.0	7.0	33	9.1	14	160	10
		Hard	1.9	6.7	27	7.4	12	85	12
	0.025	Soft	5.5	19	40	6.6	27	170	25
		Medium	5.1	18	32	5.1	25	97	26
		Hard	4.2	14	26	4.0	20	50	26
	0.10	Soft	15	38	—	—	48	60	50
		Medium	12	27	7.7	—	35	40	40
		Hard	8.6	19	16.7	5.9	24	32	34

Table XIX. Earth Penetration and Crater Formation—SAP Bombs—Continue

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
	Altitude of release, 10,000 ft.—airspeed, 250 mph—level flight								
500 lb. SAP AN-M58A2, AN-M58A1, AN-M58	0.0005 (inst.)	Soft	−0.58	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.58	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.58	−1.4	7.3	1.9	1.8	—	−3.3
	0.0027 (nondelay)	Soft	−0.067	−0.16	16	4.8	5.4	—	−0.26
		Medium	−0.060	−0.15	15	4.4	4.9	—	−0.28
		Hard	−0.053	−0.13	12	4.0	3.5	—	−0.30
	0.01	Soft	2.1	5.1	28	8.0	11	110	8.3
		Medium	2.0	5.0	25	7.1	9.9	77	9.3
		Hard	1.9	4.7	21	5.9	8.8	42	11.0
	0.025	Soft	5.5	14	33	6.2	20	123	22
		Medium	5.1	12	28	5.1	18	75	23
		Hard	5.8	10	22	3.6	35	35	24
	0.10	Soft	13	24	10	—	31	—	38
		Medium	9.7	16	22	2.1	22	—	31
		Hard	7.4	11	21	3.2	16	25	26
1,000 lb. SAP AN-M59A1, AN-M59	0.0005 (inst.)	Soft	−0.58	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.58	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.58	−1.4	7.3	1.9	1.8	—	−3.3
	0.0030 (nondelay)	Soft	−0.067	−0.16	16	4.8	5.4	—	−0.26
		Medium	−0.060	−0.15	15	4.4	4.9	—	−0.28
		Hard	−0.053	−0.13	12	4.0	3.5	—	−0.30
	0.01	Soft	2.1	5.0	33	9.6	12	190	6.4
		Medium	2.0	4.8	30	8.6	11	170	7.1
		Hard	2.0	4.6	25	7.0	9.7	76	8.5
	0.025	Soft	6.0	14	41	9.4	22	260	18
		Medium	5.6	13	36	8.1	20	170	19
		Hard	5.6	11	29	5.9	17	88	21
	0.10	Soft	16	28	18	—	37	80	37
		Medium	12	20	30	3.4	27	78	30
		Hard	8.9	14	28	4.3	19	55	25

Table XX. Earth Penetration and Crater Formation—SAP Bombs

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
	Altitude of release, 5,000 ft.—airspeed, 250 mph—level flight								
500 lb. SAP AN-M58A2, AN-M58A1, AN-M58	0.0005 (inst.)	Soft	−0.87	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.87	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.87	−1.4	7.3	1.9	1.8	—	−3.3
	0.0027 (nondelay)	Soft	−0.14	−0.22	16	4.7	5.2	—	−0.38
		Medium	−0.17	−0.26	13	4.5	5.0	—	−0.48
		Hard	−0.18	−0.29	11	3.2	3.5	—	−0.67
	0.01	Soft	2.1	3.4	25	7.4	9.2	86	5.5
		Medium	1.7	2.8	21	6.4	7.8	54	5.2
		Hard	1.5	2.4	18	4.8	6.0	28	5.6
	0.025	Soft	6.0	9.6	32	8.1	15	130	16
		Medium	5.6	8.8	28	7.0	14	84	16
		Hard	5.7	6.9	23	5.5	11	45	16
	0.10	Soft	14	16	30	4.3	23	72	27
		Medium	10	11	29	5.9	17	86	21
		Hard	7.5	7.6	23	5.5	12	45	18
1,000 lb. SAP AN-M59A1, AN-M59	0.0005 (inst.)	Soft	−0.87	−1.4	12	4.0	3.4	—	−2.3
		Medium	−0.87	−1.4	10	3.2	2.9	—	−2.6
		Hard	−0.87	−1.4	7.3	1.9	1.8	—	−3.3
	0.0030 (nondelay)	Soft	−0.14	−0.22	16	4.7	5.2	—	−0.38
		Medium	−0.17	−0.26	13	4.5	5.0	—	−0.48
		Hard	−0.18	−0.29	11	3.2	3.5	—	−0.67
	0.01	Soft	2.0	3.2	29	8.7	10	140	4.1
		Medium	1.9	3.1	26	7.8	9.4	98	4.6
		Hard	1.9	3.0	22	6.4	8.1	58	5.6
	0.025	Soft	6.1	9.8	39	11	17	250	13
		Medium	5.7	12	36	8.4	19	170	18
		Hard	4.3	6.5	28	7.4	12	85	12
	0.10	Soft	16	19	40	6.2	28	160	25
		Medium	12	14	36	7.7	20	170	20
		Hard	8.9	9	29	7.0	14	88	17

Table XX. Earth Penetration and Crater Formation—SAP Bombs—Continued

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
	Altitude of release, 4,000 ft.—airspeed, 350 mph—60° dive								
500 lb. SAP AN-M58A2, AN-M58A1, AN-M58	0.0005 (inst.)	Soft	−0.58	−1.5	12	2.7	3.0	—	−2.4
		Medium	−0.58	−1.5	10	2.8	2.9	—	−2.8
		Hard	−0.58	−1.5	8.8	2.4	2.6	—	−3.5
	0.0027 (nondelay)	Soft	−0.05	−0.12	17	4.9	5.5	23	−0.20
		Medium	−0.05	−0.13	15	4.3	4.8	15	−0.24
		Hard	−0.06	−0.14	12	3.5	4.0	8.7	−0.32
	0.01	Soft	1.6	4.2	27	7.7	9.8	100	6.8
		Medium	1.5	4.0	24	7.0	9.1	69	7.5
		Hard	1.5	3.8	20	5.6	7.7	39	8.8
	0.025	Soft	4.4	12	33	7.5	18	130	19
		Medium	4.2	11	29	6.2	16	78	20
		Hard	4.5	8.6	23	4.9	13	40	20
	0.10	Soft	11	20	21	1.2	27	50	33
		Medium	8.3	14	26	3.7	20	48	26
		Hard	6.2	9.6	23	4.3	14	42	22
1,000 lb. SAP AN-M59A1, AN-M59	0.0005 (inst.)	Soft	−0.73	−1.9	15	4.2	4.6	—	−2.4
		Medium	−0.73	−1.9	13	3.4	3.7	—	−2.8
		Hard	−0.73	−1.9	3.5	2.7	2.4	—	−3.5
	0.0030 (nondelay)	Soft	−0.11	−0.30	20	6.5	7.3	—	−0.39
		Medium	−0.12	−0.31	18	5.7	6.4	—	−0.46
		Hard	−0.12	−0.33	14	4.0	4.6	—	−0.6[illegible]
	0.01	Soft	1.5	4.0	31	9.3	11	170	5.2
		Medium	1.5	3.8	28	8.1	10	115	5.6
		Hard	1.4	3.6	23	6.8	14	66	6.7
	0.025	Soft	4.5	12	40	10	19	260	15
		Medium	4.2	11	38	9.1	18	170	16
		Hard	4.4	9.4	29	6.8	15	88	17
	0.10	Soft	13	24	31	3.1	32	110	31
		Medium	9.8	17	34	5.4	24	110	25
		Hard	7.4	12	30	5.9	17	87	21

Table XXI. Earth Penetration and Crater Formation—AP Bombs

Bomb	Fuze delay	Type of earth	Displacement feet	Depth penetrated feet	Crater measurements and type: Diameter feet	Apparent depth feet	Actual depth feet	Volume for refill cu. yd.	Crater type
Altitude of release, 20,000 ft.—airspeed, 250 mph—level flight.									
1,000 lb. AP AN-MK 33	0.08	Soft	18	50	—	0	64	10	113
		Medium	16	38	—	0	48	8	99
		Hard	13	26	—	0	34	5	78
1,600 lb. AP AN-MK 1	0.08	Soft	18	55	—	—	—	4	80
		Medium	18	44	—	—	—	3	74
		Hard	15	31	—	—	—	1	65
Altitude of release, 10,000 ft.—airspeed, 250 mph—level flight									
1,000 lb. AP AN-MK 33	0.08	Soft	19	37	—	0	48	10	83
		Medium	17	28	—	0	32	8	72
		Hard	13	19	—	0	23	5	57
1,600 lb. AP AN-MK 1	0.08	Soft	19	41	—	—	48	4	59
		Medium	19	32	—	—	38	3	53
		Hard	15	22	—	—	28	1	46
Altitude of release, 5,000 ft.—airspeed, 250 mph—level flight									
1,000 lb. AP AN-MK 33	0.08	Soft	19	26	—	0	34	10	58
		Medium	16	18	21	2	29	8	48
		Hard	15	12	21	4	12	5	45
1,600 lb. AP AN-MK 1	0.08	Soft	19	27	11	—	34	4	39
		Medium	18	22	15	—	28	3	36
		Hard	15	15	19	1.9	20	2.6	31
Altitude of release, 4,000 ft.—airspeed, 350 mph—60° dive									
1,000 lb. AP AN-MK 33	0.08	Soft	14	31	—	—	40	10	70
		Medium	14	23	—	—	29	8	59
		Hard	10	16	—	—	20	5	48
1,600 lb. AP AN-MK 1	0.08	Soft	14	36	—	—	—	4	53
		Medium	14	27	1.2	—	34	3	45
		Hard	12	19	8.8	—	24	1	39

Section VII. ARMOR PENETRATION BY BOMBS

40. General

The relatively large dispersion and low striking velocity of bor prevent the direct attack of armored targets *for perforation* from be generally profitable, except for targets of unusual importance or s However, large armor-piercing (AP) bombs dropped from high a tudes can perforate the armored decks of battleships of current constr tion. Also, the detonation of large high capacity bombs may tear arr plate of considerable thickness.

41. Deformation, Rupture and Low-Order Detonation

General-purpose (GP) and semi-armor-piercing (SAP) bombs w delay fuze do not withstand impact on heavy armor. Such an imp leads to deformation and breakage of the bomb body which generally accompanied or preceded by a low-order detonation of the explos filling (Amatol, TNT or Comp B). However, when a GP or S. bomb hits a sufficiently thin armor plate, the plate rather than the bo is deformed and ruptured so that a perforation results without effect damage to the bomb. Estimates of the plate thicknesses that can be th perforated are shown in table XXII. SAP bombs perform better th GP bombs of equal weight. Armor-piercing bombs with stand Explosive D filling withstand impact on all but the heaviest armor wi out appreciable deformation or danger of low-order detonation. T expected performance of AP bombs is shown in figure 61. Notice t use of the 1,000 pound and 1,600 pound bombs against armor thic than seven and eight inches respectively is not recommended, beca of the danger of deformation.

42. Effects of Detonation on Armor

General-purpose and, to some extent, semi-armor-piercing bombs p vided with a quick fuze achieve considerable effect when hitting arm plate of moderate thickness which would withstand the impact of same bombs with delay fuze. Estimates of the plate thicknesses th can be thus punched through, letting fragments and some of the deto tion gases pass through the plate, are shown in table XXII. Howev no substantial demolition can be thus effected on heavy structu behind the plate punched by detonation in contrast to the effect of delay-fuzed bomb which perforates and bursts behind the plate. T

detonation of uncased or lightly cased charges of TNT laid on armor produces penetrations greater than those from corresponding weights of explosive in bombs dropped on armored targets. The compactness of the charge and its proximity to the armor increases penetration. The following rule appears to hold approximately: W pounds of TNT pierces up to $\sqrt[3]{W}$ inches of armor.

43. Quality of Armor: Conversion Factors

The data given here refer to Homogeneous Armor which is also commonly referred to as "Special Treatment Steel," "Class B," or "Machinable Quality" armor. One inch thickness of this armor is roughly equivalent to 0.6–0.7 inch "Class A" or "Face Hardened" armor, to 0.9–1.0 inch of "Homogeneous Hard" armor, and to 1¼ inches of mild steel.

Table XXII. Armor Penetration by GP and SAP Bombs

Bomb	Maximum thickness[1] of plate perforated without break-up or low order detonation delay fuzing (inches)	Maximum thickness of plate punched through by detonation quick fuzing[2] (inches)
100-lb GP, AN-M30 and AN-M30A1	1.0	1.8
250-lb GP, AN-M57 and AN-M57A1	1.3	2.3
500-lb GP, AN-M64 and AN-M64A1	1.5	3.0
1,000-lb GP, AN-M65 and AN-M65A1	1.7	3.8
2,000-lb GP, AN-M66, AN-M66A1 and AN-M66A2.	2.0	4.8
500-lb SAP, AN-M58, AN-M58A1 and AN-M58A2.	2.0	2.0 (est)
1,000-lb SAP, AN-M59 and AN-M59A1 ..	2.5	2.5 (est)

[1] The perforations shown in this column can be obtained under the following conditions:
a. Against horizontal plate:
Level bombing—about 5,000 ft altitude or more
Dive bombing at 60° dive, 350 mph air speed, any altitude
b. Against vertical plate: minimum altitude bombing at 400 mph air speed
c. About 30% reduction can be expected for level bombing from 1,500 ft or for minimum altitude bombing 300 mph air speed.
d. No increase can be obtained by increasing striking velocity since, with thicker plate, break-up and low order detonation would probably occur.

[2] These perforations are obtained using an instantaneous nose fuze. Using a nondelay tail fuze should increase thickness punched through by possibly 20%.

44. Armor Penetration by AP Bomb.

The graph in figure 61 serves to determine the maximum thickness of horizontal plate perforated under typical conditions of bomb release. Graphs in figure 62 serve to determine the maximum thickness perforated under any condition of impact. The angle of impact is the angle made by the trajectory with the face of the plate. When the armor plate is horizontal, the angle of impact is the same as the angle of fall.

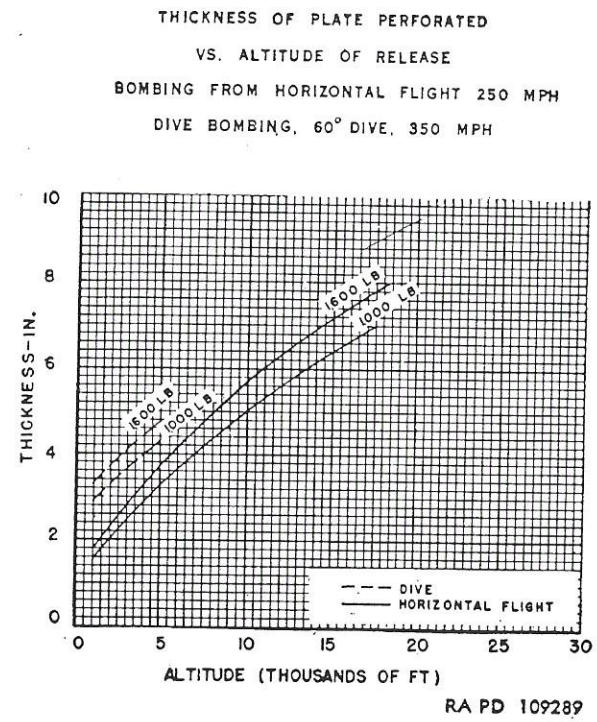


Figure 61. Armor perforation by AP bombs: thickness of plate vs altitude of release.

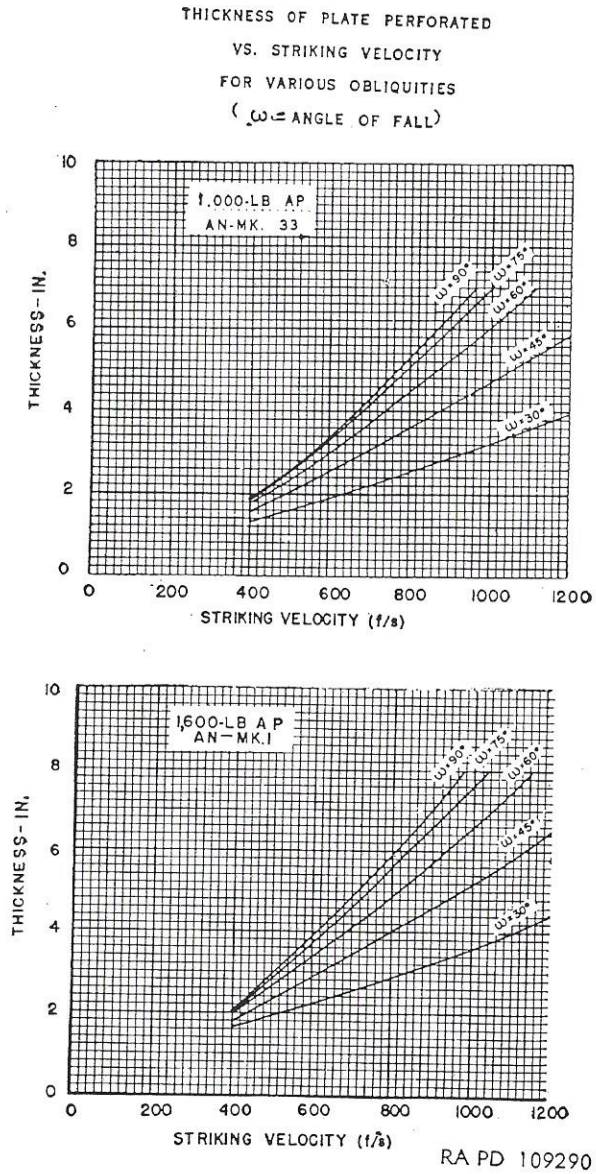


Figure 62. Thickness of plate perforated vs striking velocity—1,000-lb AP AN-Mk 33; 1,600-lb AP AN-Mk 1.

Section VIII. BOMBING OF CONCRETE

45. General

The relatively large dispersion and low striking velocities of bombs prevent the bombing of strongly built concrete fortifications from being generally profitable. Large armor-piercing bombs dropped from considerable altitude are effective in perforating all but the thicker roofs of fortifications, but the general area effect of the many unavoidable misses is negligible. On the other hand, general-purpose bombs, which are effective for area bombing of defensive positions, are generally ineffective against thick concrete because of bomb case rupture and low penetrative efficiency. Finally, semi-armor-piercing bombs are specially designed to have the largest possible charge consistent with sufficient structural strength to withstand impact stresses. Thus SAP bombs should possess optimum characteristics against concrete; however, the accompanying tables XXIII and XXIV show that the range of circumstances in which they are to be preferred to GP bombs is rather narrow. To evaluate the effort required to hit a specific target the following table may be used. The smaller numbers are based on good accuracy (15 mil); under operational conditions the larger numbers may be more realistic.

Altitude of plane (ft)		*5,000*	*10,000*	*20,000*	*30,000*
Number of bombs required to hit a 10 yd x 10 yd target with a probability of—	50%	25–250	100–1,000	400–4,000	1,000–10,000
	90%	80–800	350–3,500	1,300–13,000	3,500–35,000

46. Effect of Impact

a. GP Bombs. General-purpose bombs with a delay fuze do not withstand impact on thick concrete slabs. Such an impact leads to deformation or breakage of the casing which is generally accompanied by a low order detonation of the explosive filling (Amatol, TNT or Comp B). Breakage also is expected when a delay fuzed GP bomb strikes a strong fortification covered with a layer of earth that is somewhat thinner than the maximum earth penetration (see sec. VI, ch. 2). However, when a GP bomb hits a sufficiently thin slab, the slab rather than the bomb is ruptured so that a perforation results without effective damage to the bomb. Estimates of the slab thicknesses that can be perforated are shown in table XXIII.

b. SAP and AP Bombs. Semi-armor-piercing and armor-piercing

bombs withstand impact on strong concrete without damage that may impair their effective detonation. However, AP bombs dropped from high altitude (over 15,000 feet) are known to deform appreciably and this may somewhat reduce their penetrative ability. Estimates of the slab thickness that can be penetrated by SAP and AP bombs are shown in table XXIV. Hits against heavy concrete columns or beams result in damage impairing the effectiveness of GP but not of SAP or AP bombs.

47. Effects of Detonation on Concrete

The destructive effect achieved by the detonation of AP or SAP bombs that have not succeeded in perforating a concrete slab is small to moderate. General-purpose bombs fitted with instantaneous nose fuzes, or better, with non-delay tail fuzes, achieve a substantial effect. Tables XXIII and XXIV and figures 63 to 67 contain estimates of the total effect of impact and explosion of American bombs on concrete. Since specific quantitative data on the effects of detonation on concrete are scarce and fragmentary, extensive extrapolation was necessary in the preparation of these tables and figures.

48. Cratering in Concrete

The shallow penetration of GP and SAP bombs that do not succeed in perforating concrete slabs results in wide cracking and spalling of the front face of the slab with formation of a crater. The size of this crater is quite variable. Estimates of the expected depth are shown in the accompanying figures and tables. As a guide to the expected diameter of the crater, one may assume that it will be about four times the depth. When AP bombs succeed in penetrating deeper than 2 or 2½ feet, there is no further increase of the crater depth, but rather a bore hole slightly larger than the diameter of the bomb is formed at the bottom of the crater.

49. Back Face Effects—Scabbing

A shock travels across a concrete slab ahead of a penetrating bomb or the expanding gases that result from its detonation. As this shock is reflected from the back face of the slab, this face tends to crack with violent ejection of loose pieces of concrete and formation of a back crater. This phenomenon, called "scabbing," occurs when the bomb or its detonation products come sufficiently close to the back face and may do serious damage to personnel or light material behind the slab.

Special forms of surface steel reinforcement are sometimes used to prevent scabbing. Estimates of the maximum thickness of slab which will be scabbed under various conditions are given in the accompanying figures and tables. Complete penetration is achieved when the front face crater and the scab crater merge. The thickness of concrete slab that can be perforated is greater than the depth of penetration in a very thick slab. Heavily scabbed roofs will show considerable sag even when not blown through.

50. Rebound

A bomb that does not perforate a slab tends to rebound. It is not known how long it takes under various conditions for a bomb to penetrate and rebound the small amount necessary to render detonation ineffective against the slab. It seems probable that it will take longer than 0.025 second for a medium or large bomb to rebound this amount, but probably less than 0.1 second. It is practically certain that whenever a fuze delay in excess of 0.1 second is used, the bomb rebound will be sufficient to cause ineffective detonation.

51. Attack on a Vertical Wall

Minimum altitude attack of vertical walls generally is impracticable because of the necessity of using long delay fuzing for safety. Also the penetrating effect would be no better than that attained from 5,000 feet on horizontal roof slabs.

52. Effect of Dirt Covering Upon Concrete

Dirt covering on the roof or wall of a concrete fortification may cushion the impact of the bomb so as to reduce its penetrating power. Data on the penetration of bombs in various soils are shown in figures 59 and 60 and tables XV to XXI. A thickness of earth of 20 percent of the maximum underground trajectory of a bomb is expected to reduce its penetrating power in underlying concrete by less than 20 percent. Newly piled dirt is likely to cushion the impact of a bomb even less than wet clay.

53. Effect of Underground Detonation

The underground detonation of bombs is comparatively effective against the underground portion of concrete fortifications because of the confining effect of the earth. Figures 66 and 67 show what damage can be

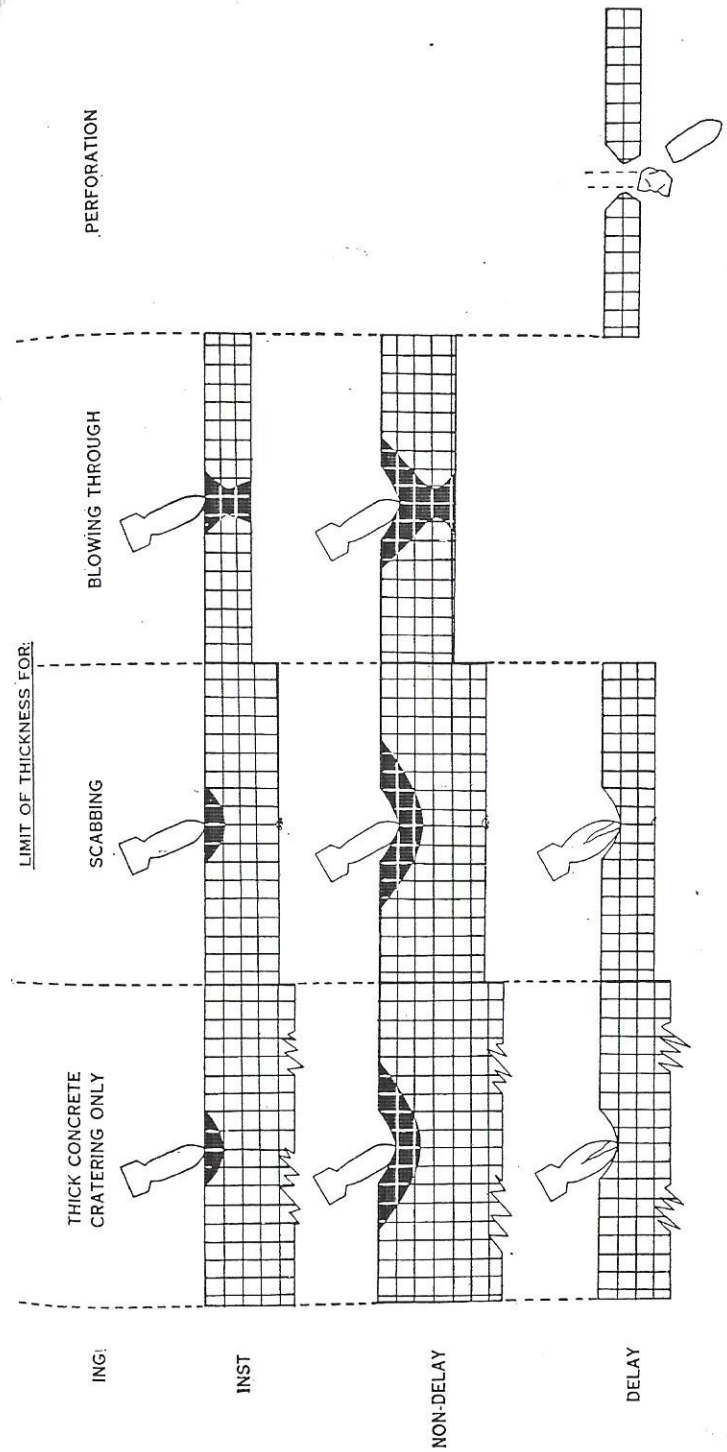
expected to result to an underground concrete slab by a given bomb detonating at a given distance. These charts assume detonation of the bomb at the depth at which the maximum crater is formed (tables XVI to XXI). The effect is reduced by at least 30 percent if the depth is 25 percent of that assumed. The difficulty with this method of attack is that the bomb must be made to detonate within a comparatively narrow region around the target, at a sufficient depth underground. In the case of GP bombs, if the concrete target is hit by the bomb before its velocity is considerably reduced, rupture of the bomb and consequent failure to detonate effectively must be expected.

Table XXIII. Effect of GP Bombs on Concrete Slabs—Dive Bombing or Level Bombing from 5,000 feet

(See figure 63 for schematic illustration of these effects. No better performance can be expected by bombing from higher altitudes because of bomb case failure.)

Bomb	Fuzing	Crater depth (ft)	Maximum thickness[2] of slab that will be—		
			Scabbed (ft)	Blown through (ft)	Perforated (ft)
100-lb GP	inst	½	2¼	1½	....
AN-M30	nondelay	1¼	3¼	2¼	....
AN-M30A1	delay[1]	½	1½	....	1
250-lb GP	inst	¾	3	1¾	....
AN-M57	nondelay	1¾	4¼	3	....
AN-M57A1	delay[1]	¾	2	....	1¼
500-lb GP	inst	1	3¾	2¼	....
AN-M64	nondelay	2¼	5¼	3¾	....
AN-M64A1	delay[1]	1	2¾	....	1¾
1,000-lb GP	inst	1¼	4¾	3	....
AN-M65	nondelay	2¾	6¾	4¾	....
AN-M65A1	delay[1]	1¼	3¼	....	2¼
2,000-lb GP	inst	1½	6	3¾	....
AN-M66					
AN-M66A1	nondelay	3½	8½	6	....
AN-M66A2	delay[1]	1½	4½	....	3

[1] No effect of detonation is included in these data, since, except for slabs under the perforation limit, the bomb is liable to break up prior to fuze operation or detonate low order.
[2] The effect indicated will occur in all slabs not thicker than the limit given.



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SHADED PORTION REPRESENTS CONCRETE REMOVED BY DETONATION

Figure 63. Schematic effect of GP bombs on concrete slabs.

Table XXIV. Effect of AP and SAP Bombs on Concrete Slabs Having a Compressive Strength of 5,000 PSI

(See figures 64 and 65 for schematic illustration of these effects. Increase these data 5–15 percent for SAP bombs and 15–30 percent for AP bombs to determine effect against medium quality concrete having a compressive strength of 3,000 psi.)

Bombs	Conditions at release	Fuzing	Crater depth (ft.)	Maximum thickness[2] of slab that will be— Scabbed (ft.)	Blown through (ft.)	Perforated (ft.)
Bomb, SAP, 500-lb., AN-M58, AN-M58A1, or AN-M58A2	Level, at 5,000 feet and 250 mph	inst	¾	3¼	2	—
		nondelay	1¾	4½	3¼	—
		delay[1]	1¾	4½	3¼	2¼
	Level, at 10,000 feet and 250 mph	inst	¾	3¼	2	—
		nondelay	2¼	5	3½	—
		delay[1]	2¼	5	3¾	3
	Level, at 20,000 feet and 250 mph	inst	¾	3¼	2	—
		nondelay	2¾	5½	4¼	—
		delay[1]	3	5¾	4½	3½
	60 degrees dive at 4,000 feet and 350 mph	inst	¾	3¼	2	—
		nondelay	2¼	4¾	3½	—
		delay[1]	2¼	5	3½	2¾
Bomb, SAP, 1,000-lb., AN-M59 or AN-M59A1	Level, at 5,000 feet and 250 mph	inst	1	4	2½	—
		nondelay	2¼	5¾	4	—
		delay[1]	2½	6	4¼	3
	Level, at 10,000 feet and 250 mph	inst	1	4	2½	—
		nondelay	2¾	6¼	4½	—
		delay[1]	3¼	6½	5	4
	Level, at 20,000 feet and 250 mph	inst	1	4	2½	—
		nondelay	3¼	6¾	5	—
		delay[1]	4	7½	6	5
	60 degrees dive, at 4,000 feet and 350 mph	inst	1	4	2½	—
		nondelay	2½	6	4¼	—
		delay[1]	3	6¼	4¾	3¾
Bomb, AP, 1,000-lb., AN-Mk 33	Level, at 5,000 feet and 250 mph	delay[1]	1½	4	3	2¾
	Level, at 10,000 feet and 250 mph	delay[1]	2½	5¼	4¼	4
	Level, at 20,000 feet and 250 mph	delay[1]	3¾	7¼	6	5¾
	Level, at 30,000 feet and 250 mph	delay[1]	4½	8¼	6¾	6½
	60 degrees dive at 4,000 feet and 350 mph	delay[1]	2¼	5¼	4	3¾
Bomb, AP, 1,600-lb., AN-Mk 1	Level, at 5,000 feet and 250 mph	delay[1]	1¾	5	3¾	3½
	Level, at 10,000 feet and 250 mph	delay[1]	3¼	6¾	5½	5¼
	Level, at 20,000 feet and 250 mph	delay[1]	5	9	7¾	7½
	Level, at 30,000 feet and 250 mph	delay[1]	6¼	11	9¼	9
	60 degrees dive, at 4,000 feet and 350 mph	delay[1]	2¾	6¼	5	4¾

[1] It is assumed that the bomb does not rebound prior to detonation. Rebound may occur, however, with a fuze delay of 0.10 sec., in which case the effect of the detonation is lost. If AP bombs with 0.08 sec. delay rebound, the loss in crater depth, scabbing limit and blow-through limit is ½ to ¼ foot.

[2] The effect indicated will occur in all slabs not thicker than the limit given.

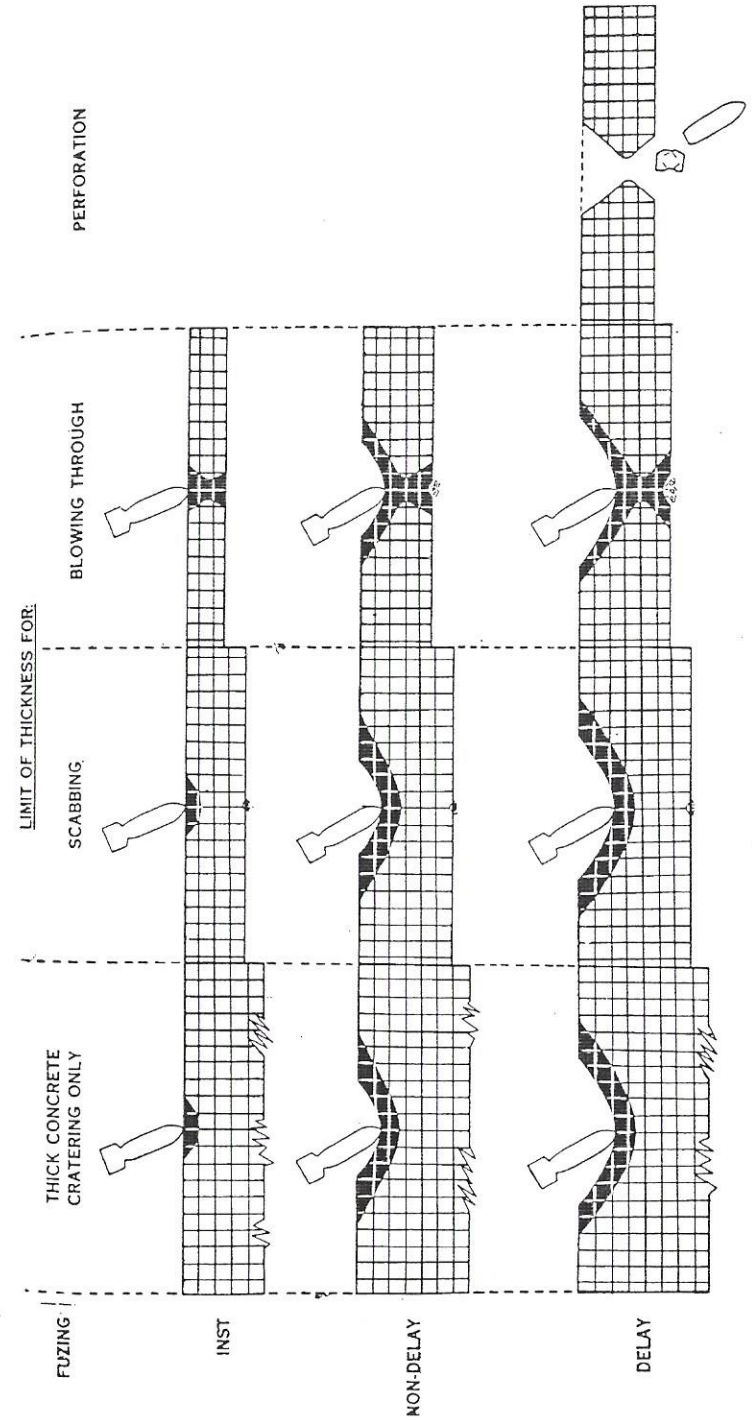
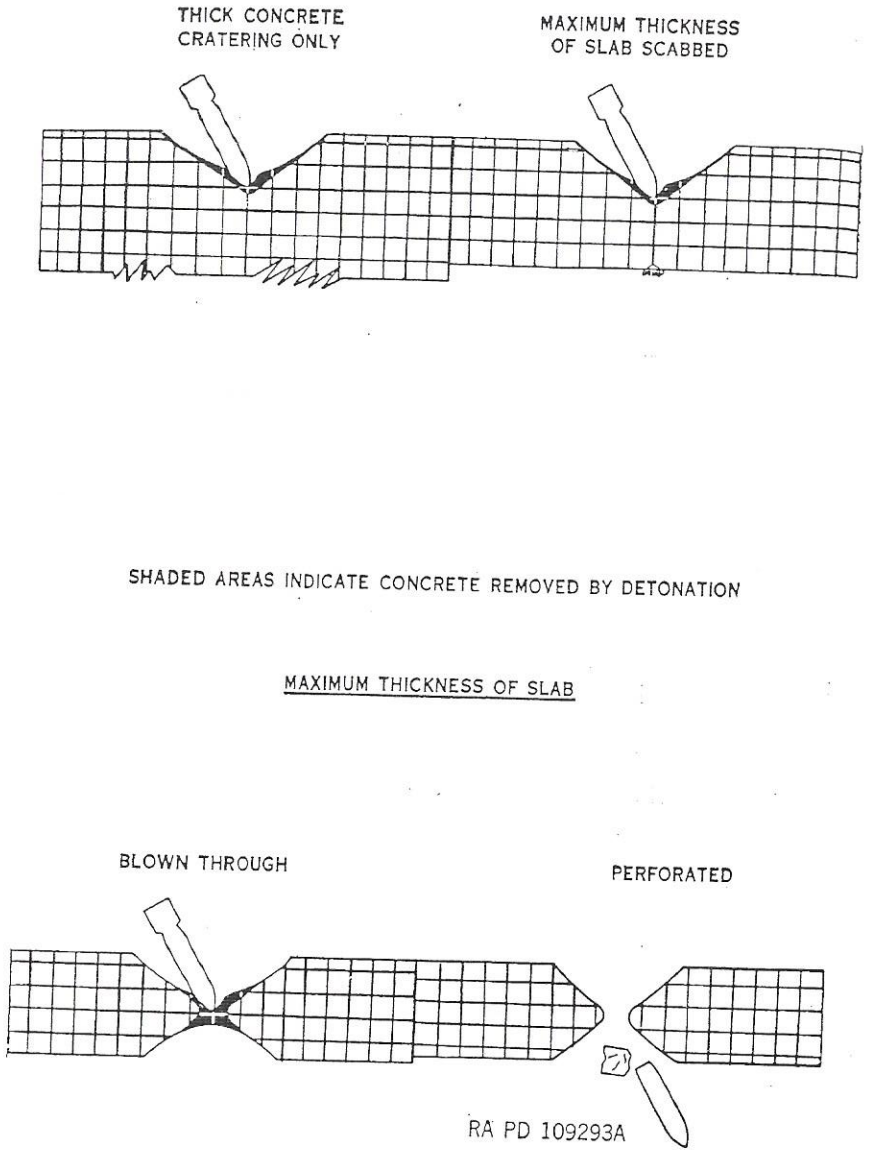


Figure 64. Schematic effect of SAP bombs on concrete slabs.



Schematic Effect of AP Bombs on Concrete Slabs

Figure 65. Schematic effect of AP bombs on concrete slabs.

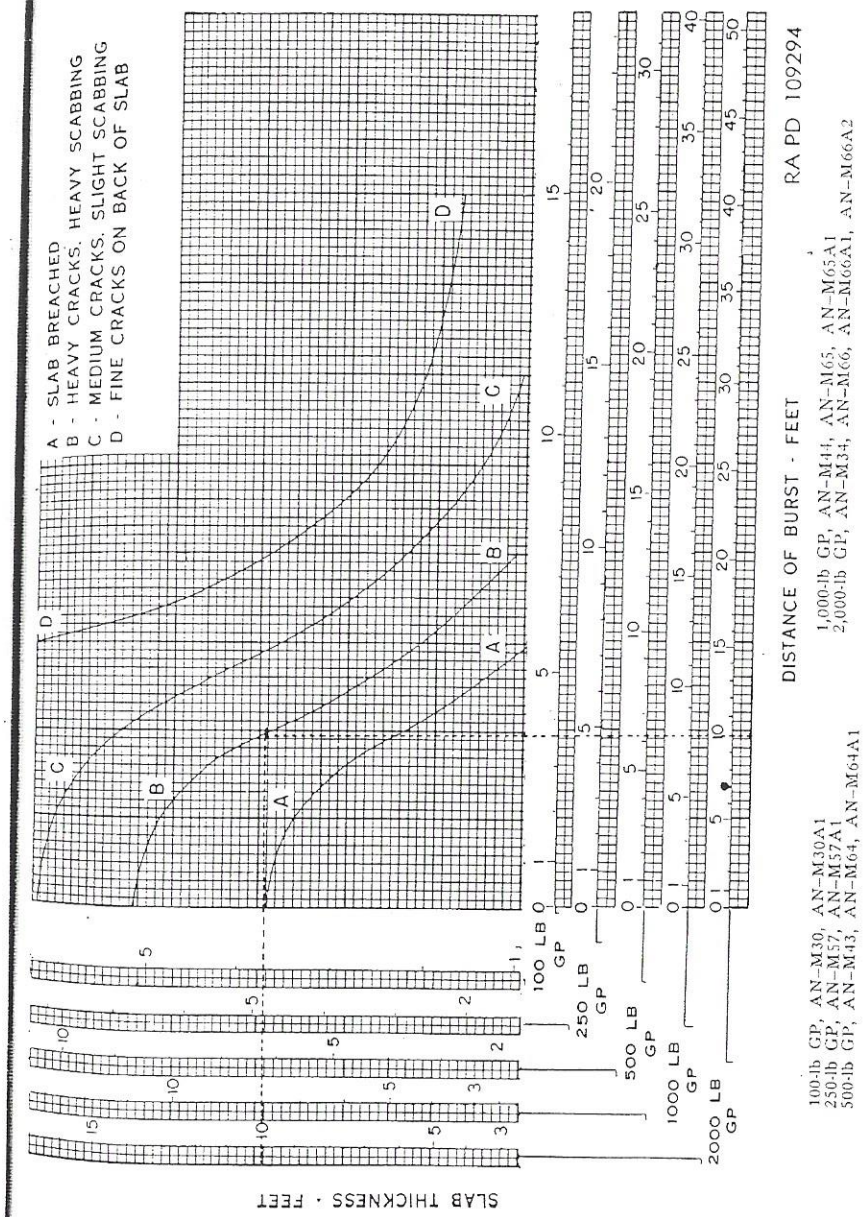


Figure 66. Bomb damage to concrete slabs.

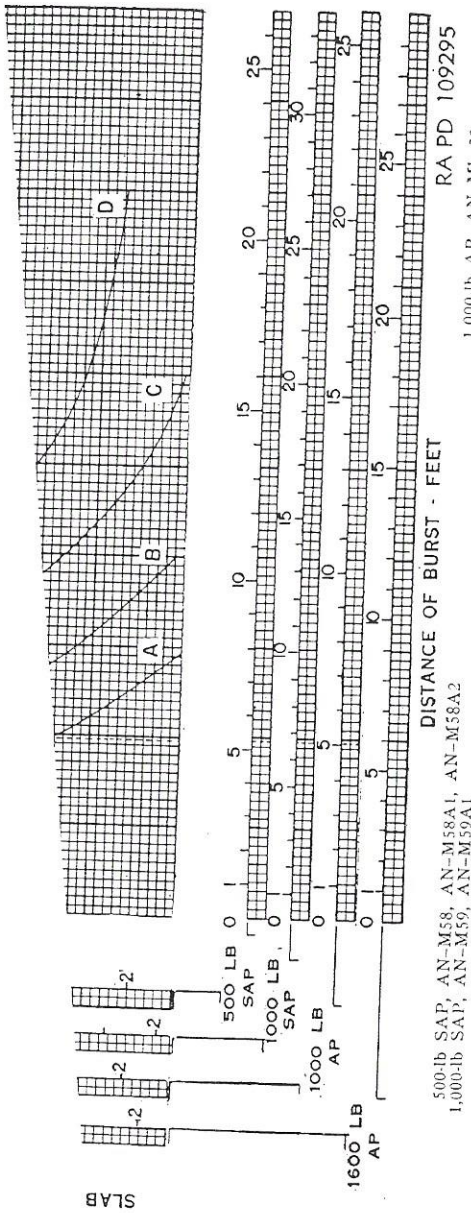


Figure 67. Bomb damage to underground concrete slabs—SAP and AP bombs.

CHAPTER THREE

PROJECTILES

Section I. SHELL FRAGMENT DAMAGE

54. General

This section presents three series of tables and charts which give data on fragmentation effect as follows:

a. Tables of Fragment Damage, which give concentration of effective fragments based on distance from burst (tables XXV to XXXIX).

b. Damage Patterns, which give distribution of effective fragments based on orientation of the projectile at time of burst (figs. 68 to 82).

c. Tables of Shell Density in Area Fire, which give number of shell required per unit area to accomplish specified effects under various conditions (figs. 83 to 95).

55. Tables of Fragment Damage

These tables give the number B of effective hits per square foot of target area at a given distance from the burst. The numbers B are averages for different directions from the burst. They are properly applied only to a considerable number of bursts with random orientation of the projectile axis relative to the target.

56. Damage Patterns

As distinguished from damage tables, the damage patterns represent typical cases and vary with the remaining velocity of the shell or rocket, the angle of fall, and the height of burst. Both damage tables and damage patterns presuppose a graze or air burst with no shielding of target. The user of the data given here must make due allowance for target shielding and the penetration of the shell or rocket into the ground before burst. The amount of this penetration will depend upon the remaining velocity, the angle of fall of the shell or rocket, the nature of the soil, and the shell or rocket, and the fuze. In the fragment damage patterns, shadings of different types indicate regions of decreasing density of hits. The regions distinguished are those where this is at least one hit per 1, 4, 10, or 25 square feet of area. These units of area

are understood as normal to the fragment trajectories. *Unshaded regions entering near the burst do not indicate that there are no effective hits in these regions, but merely that the density of effective hits is less than that belonging to the nearest shaded area. The white centers of the fragment patterns are used to indicate the origin of the polar system above which the missile bursts. In general, these areas suffer the highest type of fragment damage as well as blast damage.*

57. Types of Damage

The types of damage considered are casualties and normal perforations of mild steel of ⅛ inch, ¼ inch, and ½ inch thickness. A casualty is defined as a hit by a fragment with at least 58 foot-pounds of energy; it causes incapacitation but not necessarily death. Damage in which there is perforation of ⅛ inch mild steel is effective against airplanes on the ground. In antiaircraft fire against modern bombers, the most effective damage varies from that with ⅛ inch perforation to ⅜ inch perforation of mild steel. Damage in which there is perforation of ¼ inch or ½ inch mild steel is effective against trucks, light armored vehicles, railway rolling stock, and targets of similar resistant nature.

58. Safety Limits

The fragment damage tables are useful in determining the distance from a burst at which a soldier stands a given chance of being wounded by a fragment. Suppose, for example, that a soldier is required to take a 1-1,000 chance of being wounded by a fragment from the 105-mm HE Shell, M1. Suppose that the soldier is in open terrain in such a position that 2.5 square feet of his body are exposed to fragments coming directly from the shell. Accordingly, the number of casualty producing fragments per square foot to which the soldier is exposed is $1/1{,}000 \times 1/2.5 = 0.0004$ and by table XXXIII this fragment density occurs at a distance somewhat greater than 300 feet from the shell. Thus, *on the average* the soldier should be at a distance somewhat greater than 300 feet from the shell. If account is to be taken of the most dangerous directions from the shell, the *average densities of B of effective fragments as given in the tables* should be multiplied by a factor of about six and then used as in the above example. In the case of a man wearing standard flyer's body armor, a fragment capable of piercing the plane fuselage, the body armor, and then wounding a man, would be capable of perforating approximately ⅛ inch mild steel. Safety limits relative to hits of this type may be found by using the tables for perforations of ⅛ inch mild steel in the manner indicated in the above example.

59. Ground Bursts

a. Choice of Shell. Ground bursts are recommended in all cases where the targets are relatively unshielded. This will include most cases of matériel targets, and of personnel other than those in foxholes or prone on rough terrain. In the case of matériel targets, the artilleryman first should decide upon the type of perforation necessary to damage his target effectively. Given the type of perforation and the range, the shell, propelling charge, and elevation must be chosen. One of the factors bearing on this choice will be a knowledge of the minimum number of shell per unit area required to do the predetermined fragment damage. This can be obtained from figures 83 to 95.

b. Example. Suppose an area target given at 10,000 yards range using the 155-mm howitzer M1 and that effective damage of the target requires fragments which will perforate ¼ inch mild steel. It can be determined from figure 88 that the minimum number of shell for this range would be required if charge 5 and high angle fire are used.

60. The Required Shell Density: Ground Burst

a. Use of Charts. Let a target area be given in terms of square units of area 100 feet × 100 feet (that is, multiples of 10,000 square feet). Let it be required to wound 50 percent of the enemy personnel (4.5 square feet of area) on the given area or to damage 50 percent of matériel target elements (2 square feet of area) vulnerable to fragments of a given perforative type. The number D of shells of a given type required per unit of area (100 feet × 100 feet) is given by figures 83 to 9 against range and charge.

b. Fringe. To obtain the desired coverage of fragment effect, it is necessary to distribute shell over an area somewhat larger than the given target area. The *fringe of additional area* around the given target area has a width W indicated on each graph. This enlarged area should receive D shell per unit of area. Unless the edge of the target area is very well defined and of marked importance, it will usually be more profitable to confine the D shell per unit area to the given target area A rather than use the enlarged area. In such cases points within A at a distance at least W from the edge of A will receive the desired fragment effect. The calculations are based on a random distribution of shell over the enlarged area with an expected shell density D. The manner of achieving this shell distribution will depend on the burst dispersion and type of fire.

c. Matériel. In the case of enemy *matériel,* each target is supposed divided into a number of *elements* each 2 feet square in area and vulnerable to a hit of a given perforative type, that is, ⅛ inch, ¼ inch, or ½ inch perforation of mild steel. The figures give the number D of shell per unit required to damage effectively 50 percent of these target ele

ments. For example, an enemy vehicle may present eight of these target elements vulnerable to hits capable of perforating ⅛ inch mild steel. If the shell density is taken from figures 83 to 91 for ⅛ inch perforations, four of these eight target elements may be expected to be damaged effectively. As in the case of casualties, the distribution of shell with the density D must be made over an area somewhat larger than the given target area. The width W of this additional fringe of area is indicated on the figure.

d. Conversion Factors. (1) *Percentage.* If the percent of target elements which it is desired to damage effectively is not 50 percent, it is sufficient to multiply the shell density given in the figures by a factor F given in paragraph 61 to obtain the correct shell density D.

(2) *Shielding.* The shell densities D are calculated for flat unshielded terrain and, in the case of personnel, for men who are standing. For prone men or for terrain which is rolling or shielded, the shell densities should be multiplied by appropriate factors. Estimates for some of the more important cases are given in paragraph 61.

e. Blast. Blast is effective against personnel in the open for relatively small distances which, in every case, are considerably less than those at which a casualty is certain to be caused by fragments.

f. Example. Let the target area be 500 feet × 1,000 feet and at 5,000 yards and suppose it is desired to wound 60 percent of the enemy personnel on the area using the 105-mm HE Shell, M1 and charge 4, high angle fire. Suppose the terrain is flat and unshielded. *Solution.* The width W of the additional fringe of area is 58 feet according to figure 87. The enlarged target dimensions are 616 feet × 1,116 feet. Thus, the enlarged area contains 69 units of area. For each of these units, 0.58 shell are required in accordance with figure 87 to produce 50 percent casualties. Since the percent of wounded is to be 60 instead of 50, a factor of 1.32 is called for as given in paragraph 61. Thus, the number of shell which should be distributed over the enlarged area is 69 × 0.58 × 1.32 = 53.

61. Conversion Factors for Density Data

Figures 83 to 91 give the shell densities D per unit area (100 feet by 100 feet) required to cause damage of the type specified on the graph. To obtain P percent casualties or damage to P percent of the matériel target elements, the values of D obtained from the graphs should be multiplied by the factor F given in the following table under P:

Percent P	10	20	30	40	50	60	70	80	90
The factor F	0.150	0.322	0.516	0.740	1.00	1.32	1.74	2.32	3.32

In case the target area is not flat or is shielded, or the men are not standing, the above values of D should be multiplied by an appropriate factor. Estimates of this factor are given below for a number of typical cases.

Men		*Matériel*	
Factor	*The Tactical Case*	*Factor*	*The Tactical Case*
3	Men prone, flat terrain, no shielding.	2	Rolling terrain, no shielding.
2	Men standing, rolling terrain, no shielding.	3	Rolling terrain, rough country.
4	Men prone, rolling terrain, country fields.		

62. Air Bursts: Types of Shielding

Air bursts are recommended against men in foxholes or open trenches and against personnel shielded by rough terrain. The type of shielding labeled 10° foxholes is believed to be that most commonly encountered and will correspond to the shielding afforded men in foxholes when the men are somewhat below the level of the ground (fig. 33) or to the shielding afforded prone men by rough terrain. The term 10° foxhole arose from its definition as a foxhole in which an occupant will on the average be unharmed by fragments with an angle of fall less than 10 degrees. Hastily dug in positions on level ground will correspond to 0° foxholes, as will trenches in which the heads of men are even with the ground. Men in 30° foxholes are relatively safe from attack by high explosive shell, even by air burst fire. In general, figures 92 to 95 are drawn for 10° foxholes. In the case of 0° and 30° foxholes, figures are given for the 105-mm howitzer only (fig. 94) and will serve as a guide for other guns and shell.

63. The Choice of Shell: Air Burst

a. Use of Charts. Given the range, figures 92 to 95 will show which weapon and which charge will obtain a 50 percent casualty effect with the minimum number of bursts per unit area. With the range, gun, shell, and propelling charge determined, the artilleryman can use the firing tables to obtain the probable error in the height of burst. This will be needed in rule A which follows.

b. Height of Burst. For the shells considered, the optimum height of burst against shielded personnel is for the most part between 25 and 50 feet. This optimum is for a controlled height of burst without dispersion in height. In actual practice the height of burst of a shell in time fire suffers considerable dispersion and the best *mean* height of burst is generally higher than the best controlled height. The following practical rule assures fragment damage near the optimum against enemy personnel in medium foxholes:

Rule A

Adjust the mean height H of burst to a value which is twice the probable error in the height of burst as listed in the firing tables, restricting H, however, to values between 30 feet and 120 feet.

64. The Required Shell Density: Air Burst

a. USE OF CHARTS. As in the case of ground bursts, the target area is given in terms of units of area (100 feet × 100 feet). Once the range, weapon, and charge have been chosen, figures 92 to 95 give the number D of air bursts per unit of area required to cause 50 percent casualties with the type of shielding indicated on the figure. It is assumed that the mean height of burst has been adjusted in accordance with rule A.

b. FRINGE. As in the case of ground bursts, it is necessary to distribute D bursts per unit area not only over the given target area but also over a somewhat larger area. To this end rule B may be used.

Rule B

The width W (feet) of the additional fringe of area is approximately equal to the mean height H of burst, as prescribed by rule A, plus 10 feet except in the case of the 155-mm howitzer in which case take W = 2H.

c. CONVERSION FACTORS. If the percent casualties desired is P and not 50 percent it is sufficient, as in the case of ground bursts, to multiply the shell density D given in the graphs by the factor F given in paragraph 61.

d. EXAMPLE. (1) *Given*: An area target 100 feet × 500 feet, consisting of men in 10° foxholes, let it be required to wound 20 percent of the enemy personnel in the area using the 105-mm howitzer, M2A1 and shell, HE, M1. Suppose the range is 5,000 yards.

(2) *Solution.* For a range of 5,000 yards and for charge 7, the firing table gives a probable error in the height of burst of 1 mil or 15 feet. Following rule A, adjust the mean height H of burst to a value which is twice the probable error in the height of burst as listed in the firing tables, restricting H, however, to values between 30 feet and 120 feet. This gives H = 30 feet. According to rule B, the width of additional fringe required is 30 + 10 = 40 feet, so that the total area to be covered is 180 feet × 580 feet or 11 units (100 feet × 100 feet). Figure 94 shows that 7.5 shells are required per unit area so that 7.5 × 11 = 82.5 shells must be distributed over the enlarged area to obtain 50 percent casualties. To obtain 20 percent casualties, it appears from paragraph 61 that 82.5 × 0.322 = 27 shells should be distributed.

Table XXV. Fragment Damage of Grenade, Hand, Mk 2; TNT Loading; Initial Fragment Velocity, 1,800 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
		Casualties		
10	158	.126	.0264	1500
20	106	.0211	.0352	1300
30	74	.00654	.0440	1160
40	53	.00264	.0525	1060
50	40	.00127	.0597	997
60	31	.00069	.0664	946
70	24	.00039	.0725	905
80	19	.00024	.0785	870
90	15	.00015	.0843	839
100	12	.00010	.0902	811
110	8	.00005	.0957	788

Table XXVI. Fragment Damage of Shell, HE, 20-mm, T16; Initial Fragment Velocity 2,000 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
		Casualties		
5	38	.121	.0182	1810
10	31	.0247	.0217	1650
15	26	.00920	.0255	1530
20	21	.00418	.0295	1420
30	14	.00124	.0381	1250
40	8	.00040	.0466	1130

Table XXVII. Fragment Damage of Shell, HEI, 20-mm, M97; Initial Fragment Velocity 1,800 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
		Casualties		
5	33	.105	.0224	1630
10	27	.0215	.0264	1500
15	22	.00778	.0307	1390
20	19	.00378	.0352	1300
30	14	.00124	.0440	1160
40	10	.00050	.0525	1060

Table XXVIII. Fragment Damage of Shell, HE, 75-mm, M48; Initial Fragment Velocity 3,120 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	950	.189	.0133	2110
30	850	.0752	.0182	1810
40	755	.0375	.0238	1580
60	615	.0136	.0367	1270
80	525	.00653	.0504	1090
100	460	.00366	.0624	976
150	365	.00129	.0891	816
200	326	.00065	.115	719
300	256	.00023	.175	583
400	196	.00010	.246	491
Perforation of ⅛ inch mild steel				
20	550	.109	.0458	2420
30	470	.0416	.0602	2190
40	400	.0199	.0780	2020
60	310	.00685	.124	1750
80	250	.00311	.182	1560
100	195	.00155	.248	1430
150	102	.00036	.456	1190
200	53	.00011	.695	1050
300	18	.00002	1.17	910
Perforation of ¼ inch mild steel				
20	186	.0370	.266	2730
30	158	.0140	.315	2570
40	132	.00656	.368	2450
60	92	.00203	.492	2210
80	62	.00077	.635	2030
100	41	.00033	.805	1880
110	33	.00022	.898	1820
120	26	.00014	1.00	1760
130	20	.00009	1.12	1690
150	11	.00004	1.34	1600

Table XXIX. Fragment Damage of Shell, HE, 76-mm, M42A1; Initial Fragment Velocity 2,260 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	560	.111	.0241	1570
30	500	.0442	.0315	1370
40	460	.0229	.0396	1220
60	400	.00884	.0546	1040
80	365	.00454	.0675	938
100	338	.00269	.0790	867
150	288	.00102	.106	748
200	250	.00050	.134	666
300	189	.00017	.204	540
400	145	.00007	.285	456
Perforation of ⅛ inch mild steel				
20	285	.0567	.108	1830
30	240	.0212	.142	1680
40	205	.0102	.180	1560
60	152	.00336	.272	1390
80	115	.00143	.373	1260
100	89	.00071	.482	1170
130	62	.00029	.656	1070
160	44	.00014	.826	1000
190	31	.00007	.990	940
Perforation of ¼ inch mild steel				
5	85	.271	.504	2200
10	77	.0613	.552	2140
15	70	.0248	.598	2080
20	63	.0125	.650	2020
30	51	.00451	.758	1920
40	40	.00199	.874	1840
50	29	.00092	1.02	1740
60	22	.00049	1.16	1680
70	16	.00026	1.30	1610
80	10	.00012	1.48	1560

Table XXX. Fragment Damage of Shell, HE, 81-mm, M43A1; Initial Fragment Velocity 3,930 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	820	.163	.0088	2600
30	740	.0654	.0122	2210
50	610	.0194	.0207	1690
60	560	.0124	.0260	1510
80	460	.00572	.0378	1250
100	380	.00302	.0502	1090
150	258	.00091	.0772	877
200	185	.00037	.0997	772
300	78	.00007	.158	613
Perforation of ⅛ inch mild steel				
20	545	.108	.0266	2970
30	470	.0416	.0358	2660
50	335	.0107	.0584	2220
60	275	.00608	.0724	2070
80	156	.00194	.110	1820
100	82	.00065	.154	1640
120	55	.00030	.206	1510
140	38	.00015	.266	1400
180	22	.00005	.406	1230
Perforation of ¼ inch mild steel				
20	87	.0173	.150	3370
30	65	.00575	.178	3160
50	42	.00134	.248	2800
60	35	.00077	.285	2660
80	25	.00031	.370	2450
90	21	.00021	.420	2330
100	18	.00014	.475	2240
110	15	.00010	.532	2160
120	13	.00007	.591	2080
140	9	.00004	.722	1950

Table XXXI. Fragment Damage of Shell, HE, 81-mm, M56; Initial Fragment Velocity 6,180 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	2600	.517	.0043	3720
30	2000	.177	.0061	3120
50	1240	.0395	.0107	2360
60	980	.0217	.0135	2100
80	620	.00771	.0207	1690
100	410	.00326	.0292	1430
150	172	.00061	.0548	1040
200	100	.00020	.0784	870
300	63	.00006	.125	689
Perforation of ⅛ inch mild steel				
20	1320	.263	.0099	4200
30	930	.0822	.0141	3720
50	490	.0156	.0250	3030
60	380	.00840	.0313	2820
80	218	.00271	.0465	2400
100	132	.00105	.0658	2130
150	58	.00021	.137	1710
200	29	.00006	.241	1440
300	10	.00001	.532	1130
Perforation of ¼ inch mild steel				
20	184	.0366	.0532	4980
30	130	.0115	.0662	4680
50	78	.00248	.0968	3990
60	68	.00150	.114	3740
80	52	.00065	.154	3330
100	39	.00031	.198	3040
150	18	.00006	.338	2510
180	12	.00003	.452	2270
200	10	.00002	.536	2150

Table XXXII. Fragment Damage of Shell, HE, 90-mm, M71; Initial Fragment Velocity 2,900 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	672	.134	.0153	1970
30	608	.0538	.0207	1690
50	512	.0163	.0335	1330
60	480	.0106	.0408	1210
80	432	.00537	.0544	1040
100	400	.00318	.0663	946
150	352	.00124	.0930	799
200	320	.00064	.120	704
300	268	.00024	.182	571
500	202	.00006	.342	417
Perforation of ⅛ inch mild steel				
20	430	.0855	.0546	2270
30	388	.0343	.0724	2070
50	320	.0102	.120	1820
60	288	.00641	.148	1660
80	250	.00311	.215	1490
100	216	.00172	.293	1360
150	158	.00056	.520	1140
200	108	.00021	.771	1020
300	54	.00005	1.27	890
500	20	.00001	2.45	745
Perforation of ¼ inch mild steel				
20	208	.0414	.324	2550
30	192	.0170	.380	2410
50	158	.00503	.520	2170
60	140	.00309	.595	2080
80	110	.00137	.762	1910
100	81	.00064	.962	1770
150	39	.00014	1.57	1520
200	21	.00004	2.34	1360
250	13	.00002	3.20	1240
275	10	.00001	3.68	1190

Table XXXIII. Fragment Damage of Shell, HE, 105-mm, M1; Initial Fragment Velocity 3,500 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	1010	.201	.0108	2340
30	1005	.0889	.0148	2000
50	980	.0312	.0249	1540
60	956	.0211	.0310	1380
80	904	.0112	.0440	1160
100	856	.00681	.0562	1030
150	768	.00272	.0832	845
200	672	.00134	.109	738
300	516	.00046	.166	598
400	414	.00021	.235	503
500	356	.00011	.315	434
Perforation of ⅛ inch mild steel				
20	950	.189	.0350	2690
30	900	.0796	.0460	2410
50	790	.0251	.0752	2040
60	735	.0162	.0940	1910
80	580	.00721	.139	1690
100	480	.00382	.195	1530
150	318	.00112	.370	1260
200	210	.00042	.590	1100
300	88	.00008	1.05	935
400	47	.00002	1.52	845
500	23	.00001	2.07	775
Perforation of ¼ inch mild steel				
20	478	.0951	.197	3040
30	424	.0375	.236	2850
50	348	.0111	.324	2550
60	315	.00696	.372	2430
80	250	.00311	.485	2220
100	198	.00158	.614	2060
150	93	.00033	1.02	1740
200	44	.00009	1.55	1530
250	19	.00002	2.20	1380
275	12	.00001	2.56	1330

Table XXXIV. Fragment Damage of Shell, HE, 120-mm, M73; Initial Fragment Velocity 2,900 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	1010	.201	.015	1970
30	935	.0827	.021	1690
40	870	.0433	.027	1490
60	760	.0168	.041	1210
80	690	.0086	.054	1040
100	635	.0051	.066	946
150	550	.0019	.093	799
200	490	.0010	.120	704
300	400	.0004	.182	571
400	338	.0002	.256	482
500	290	.0001	.342	417
Perforation of ⅛ inch mild steel				
20	680	.135	.055	2270
30	610	.0539	.072	2070
40	550	.0274	.094	1910
60	445	.0098	.148	1660
80	370	.0046	.215	1490
100	315	.0025	.293	1360
120	275	.0015	.377	1260
140	245	.0010	.472	1180
170	210	.0006	.622	1090
200	187	.0004	.771	1020
300	135	.0001	1.27	890
Perforation of ¼ inch mild steel				
20	300	.0597	.324	2550
30	275	.0243	.380	2410
40	252	.0125	.445	2290
60	215	.00475	.595	2080
80	187	.00233	.762	1910
100	153	.00122	.962	1770
120	142	.00078	1.18	1660
150	115	.00041	1.57	1520
200	80	.00016	2.34	1360
275	46	.00005	3.68	1190

Table XXXV. Fragment Damage of Shell, HE, 155-mm, M107; Initial Fragment Velocity 3,500 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	1880	.374	.0108	2340
30	1740	.154	.0148	2000
40	1640	.0816	.0195	1740
60	1450	.0321	.0310	1380
80	1300	.0162	.0440	1160
100	1220	.00971	.0562	1030
150	1040	.00368	.0832	845
200	940	.00187	.109	738
300	770	.00068	.166	598
400	640	.00032	.235	503
700	420	.00007	.515	340
Perforation of ⅛ inch mild steel				
20	1400	.278	.0350	2690
30	1290	.114	.0460	2410
40	1210	.0602	.0591	2210
60	990	.0219	.0940	1910
80	840	.0104	.139	1690
100	720	.00573	.195	1530
150	500	.00177	.370	1260
200	390	.00078	.590	1100
300	280	.00025	1.05	935
400	220	.00011	1.52	845
700	72	.00001	3.44	685
Perforation of ¼ inch mild steel				
20	710	.141	.198	3040
30	676	.0598	.236	2850
40	600	.0298	.277	2680
60	510	.0113	.372	2430
80	440	.00547	.485	2220
100	385	.00306	.614	2060
120	336	.00186	.760	1920
140	300	.00122	.932	1800
160	265	.00082	1.12	1690
180	240	.00059	1.32	1610
200	212	.00042	1.55	1530
300	88	.00008	2.75	1270

Table XXXVI. Fragment Damage of Shell, HE, 8 inch, M103; Initial Fragment Velocity 2,500 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	1920	.382	.0200	1720
30	1840	.163	.0265	1500
50	1700	.0541	.0416	1200
60	1620	.0358	.0492	1100
100	1480	.0118	.0740	896
150	1360	.00481	.101	767
200	1260	.00251	.129	678
300	1100	.00097	.195	552
500	852	.00027	.365	403
700	700	.00011	.591	317
Perforation of ⅛ inch mild steel				
20	1450	.288	.0808	1990
30	1340	.118	.108	1830
50	1140	.0363	.174	1580
60	1060	.0234	.213	1490
100	820	.00652	.395	1240
150	665	.00235	.665	1070
200	565	.00112	.932	970
300	435	.00038	1.46	860
500	270	.00009	2.74	720
700	180	.00003	4.46	640
Perforation of ¼ inch mild steel				
20	760	.151	.490	2210
30	710	.0628	.573	2110
50	625	.0199	.762	1910
60	585	.0129	.872	1840
100	445	.00354	1.40	1580
150	318	.00112	2.20	1380
200	248	.00049	3.18	1240
300	152	.00013	5.30	1070
400	108	.00005	7.44	975
500	77	.00002	9.58	900
Perforation of ½ inch mild steel				
20	242	.0481	3.29	2350
30	225	.0199	3.58	2280
50	190	.00605	4.25	2150
60	178	.00393	4.58	2100
100	130	.00103	6.18	1910
120	115	.00061	7.05	1830
140	98	.00040	8.00	1760
160	83	.00026	9.00	1690
180	70	.00017	10.00	1640

Table XXXVII. Fragment Damage of Shell, HE, 240-mm, M114; Initial Fragment Velocity 3,300 f/s

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	4200	.836	.0121	2220
30	4000	.354	.0164	1900
50	3680	.117	.0274	1470
60	3510	.0776	.0337	1330
100	3080	.0245	.0595	999
150	2760	.00976	.0862	830
200	2540	.00505	.113	725
300	2220	.00196	.172	588
500	1760	.00056	.324	428
700	1450	.00024	.528	335
Perforation of ⅛ inch mild steel				
20	3400	.676	.0400	2550
30	3150	.279	.0525	2300
50	2800	.0891	.0863	1960
60	2570	.0568	.108	1830
100	2050	.0163	.222	1470
150	1620	.00573	.412	1220
200	1330	.00264	.640	1080
300	925	.00082	1.12	920
500	500	.00016	2.18	765
700	335	.00005	3.62	675
Perforation of ¼ inch mild steel				
20	2000	.398	.230	2860
30	1880	.166	.274	2690
50	1700	.0541	.370	2450
60	1580	.0349	.430	2310
100	1270	.0101	.702	1960
150	910	.00322	1.17	1670
200	610	.00121	1.76	1470
300	360	.00032	3.30	1220
400	265	.00013	5.13	1080
500	190	.00006	7.00	990
Perforation of ½ inch mild steel				
20	695	.138	1.58	3050
30	630	.0557	1.72	2960
50	530	.0169	2.04	2780
60	500	.0111	2.20	2710
100	385	.00306	3.00	2420
150	304	.00108	4.18	2170
200	248	.00049	5.66	1960
250	170	.00022	7.38	1810
275	128	.00013	8.38	1730
300	76	.00007	9.38	1670

Table XXXVIII. Fragment Damage of Rocket, HE, 4.5-in., T22; Initial Fragment Velocity 3,500 f/s

(Remaining velocity, 500 f/s; nose section (limits 0° and 70° from nose))

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	360	.218	.0108	2340
30	304	.0817	.0148	2000
40	260	.0393	.0195	1740
60	192	.0129	.0310	1380
80	149	.00563	.0440	1160
100	121	.00293	.0562	1030
150	96	.00103	.0832	845
200	90	.000544	.109	738
300	73	.000196	.166	598
400	55	.000083	.235	503
Perforation of ⅛ inch mild steel				
20	175	.106	.0350	2690
30	142	.0382	.0460	2410
40	115	.0174	.0591	2210
60	93	.00625	.0940	1910
80	82	.00310	.139	1690
100	65	.00157	.195	1530
150	35	.00038	.370	1260
200	22	.00013	.590	1100
300	10	.00003	1.05	935
400	4	.00001	1.52	845
Perforation of ¼ inch mild steel				
20	64	.0387	.197	3040
30	54	.0145	.236	2850
40	47	.00711	.277	2680
60	35	.00235	.372	2430
80	27	.00102	.425	2220
100	21	.00051	.614	2060
120	18	.00030	.760	1920
150	11	.00012	1.02	1740
200	4	.00002	1.55	1530
225	3	.00001	1.86	1450

Table XXXIX. Fragment Damage of Rocket, HE, 4.5-in, T22; Initial Fragment Velocity 4,000 f/s

(Remaining velocity, 500 f/s; side wall section (70° to 120° from nose))

Dist from burst in feet	Total number of effective fragments	Average number of effective fragments per sq ft	For the lightest effective fragment	
			Weight ozs	Vel f/s
r	N	B	m	v
Casualties				
20	880	.416	.0086	2630
30	752	.158	.0119	2230
40	650	.0768	.0157	1940
60	482	.0253	.0255	1530
80	370	.0109	.0368	1270
100	292	.00552	.0493	1100
150	220	.00185	.0763	882
200	201	.00095	.100	771
300	169	.00035	.156	617
400	126	.00015	.220	520
Perforation of ⅛ inch mild steel				
20	480	.227	.0256	3010
30	390	.0819	.0346	2700
40	320	.0378	.0446	2450
60	230	.0121	.0697	2090
80	200	.00591	.104	1850
100	175	.00331	.147	1670
150	98	.00082	.290	1360
200	60	.00028	.474	1170
300	30.	.00006	.904	980
400	17	.00002	1.36	880
Perforation of ¼ inch mild steel				
20	177	.0836	.144	3420
30	158	.0332	.172	3200
40	135	.0159	.203	3000
60	103	.00541	.275	2690
80	80	.00236	.358	2460
100	62	.00117	.457	2260
120	49	.00064	.570	2110
150	36	.00030	.766	1910
200	21	.00010	1.19	1660
225	15	.00006	1.43	1570

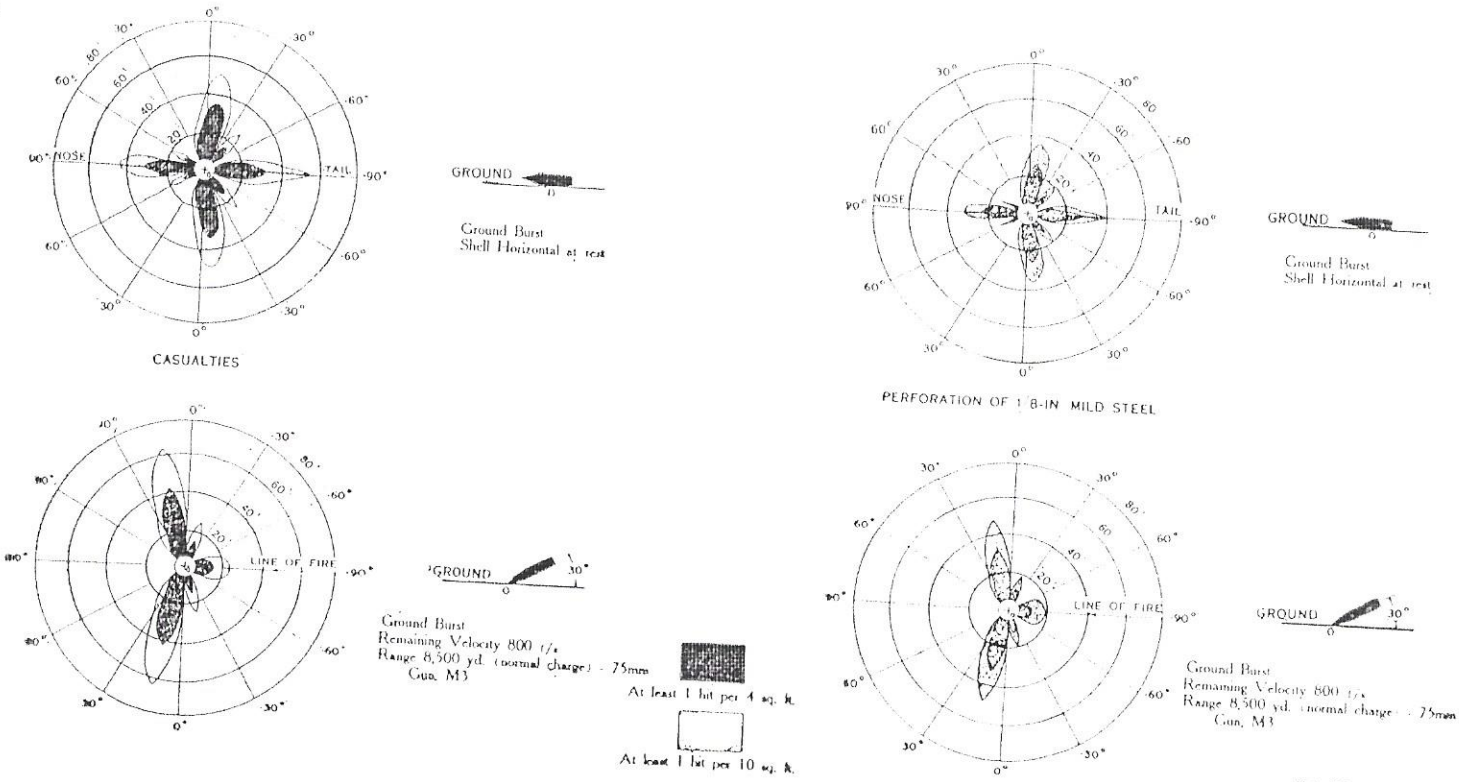


Figure 68. Damage pattern—75-mm HE shell, M48.

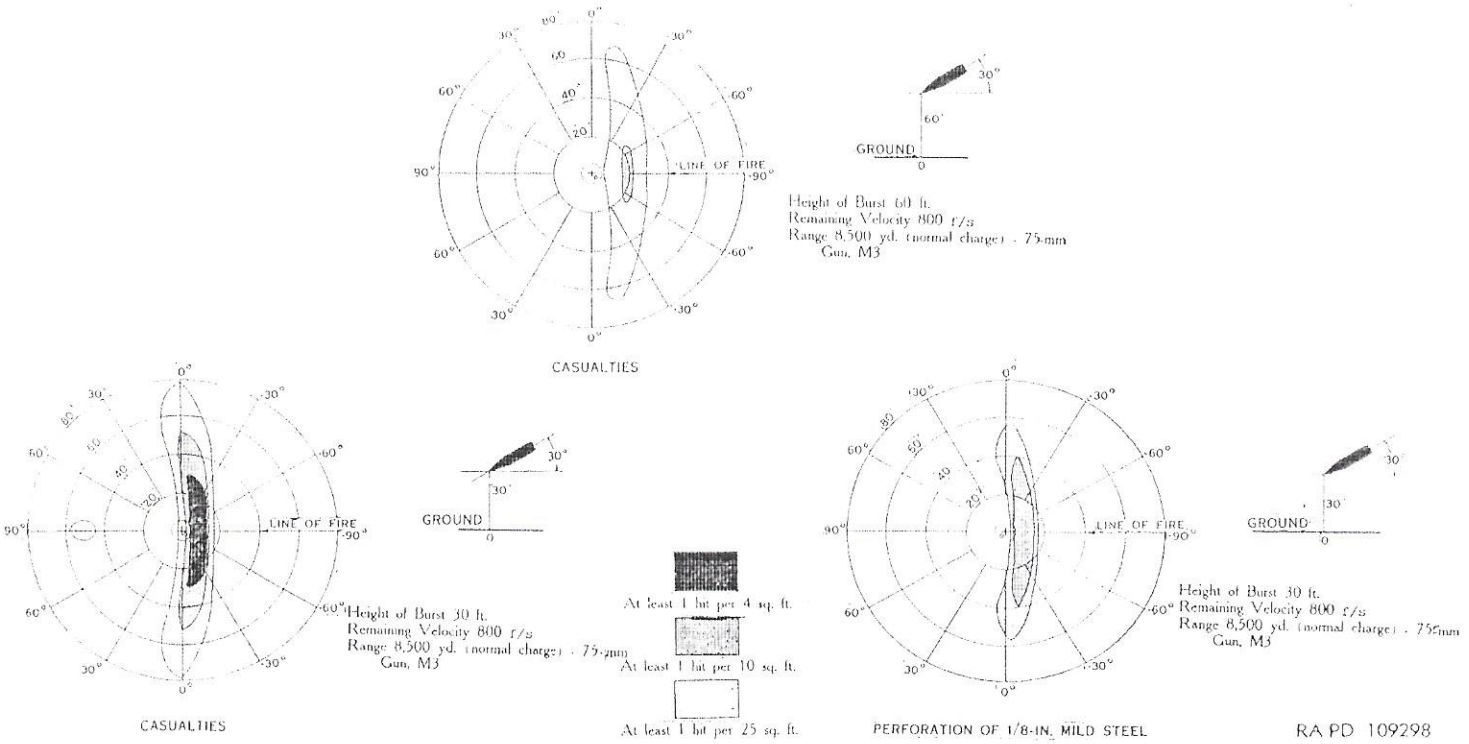


Figure 69. Damage Pattern—75-mm HE shell, M48.

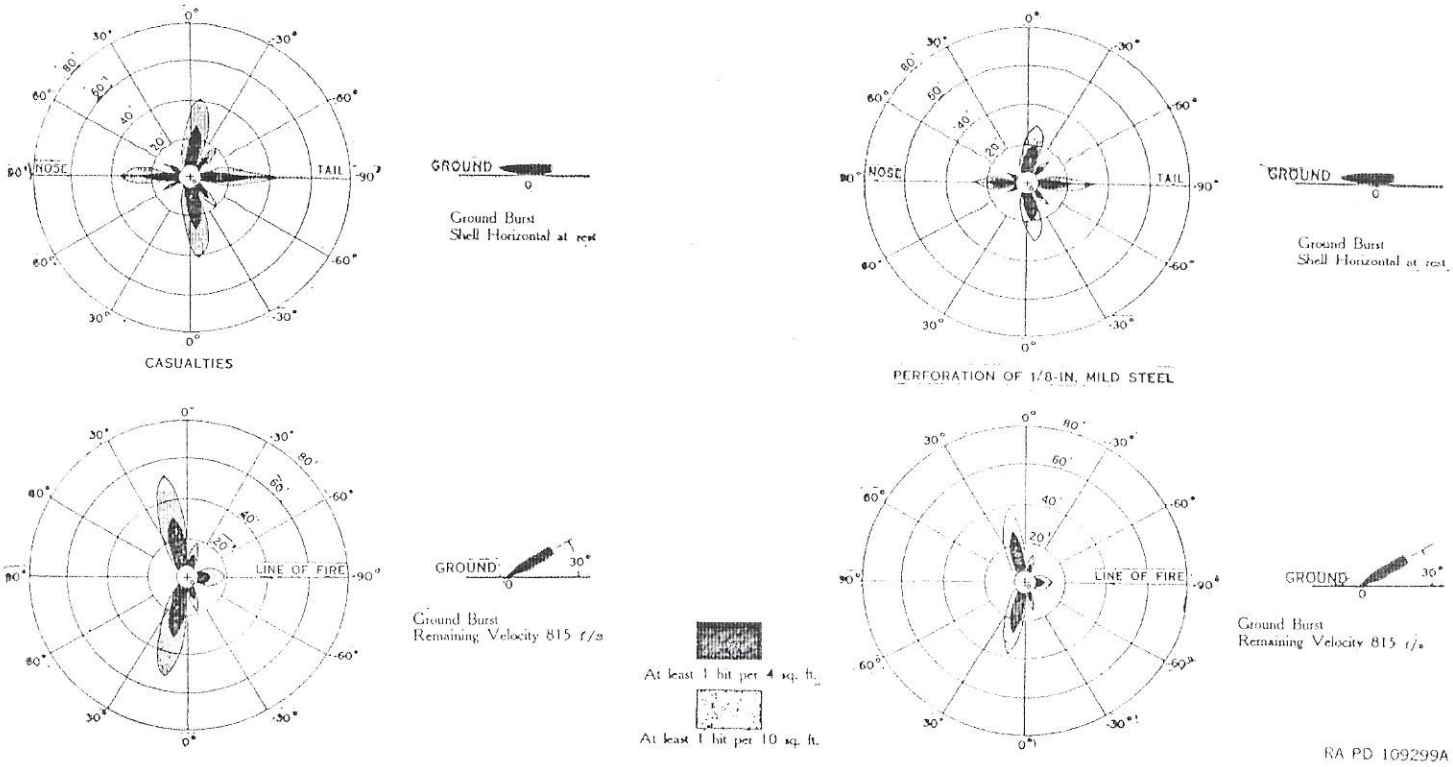


Figure 70. Damage pattern—76-mm HE shell, M42A1.

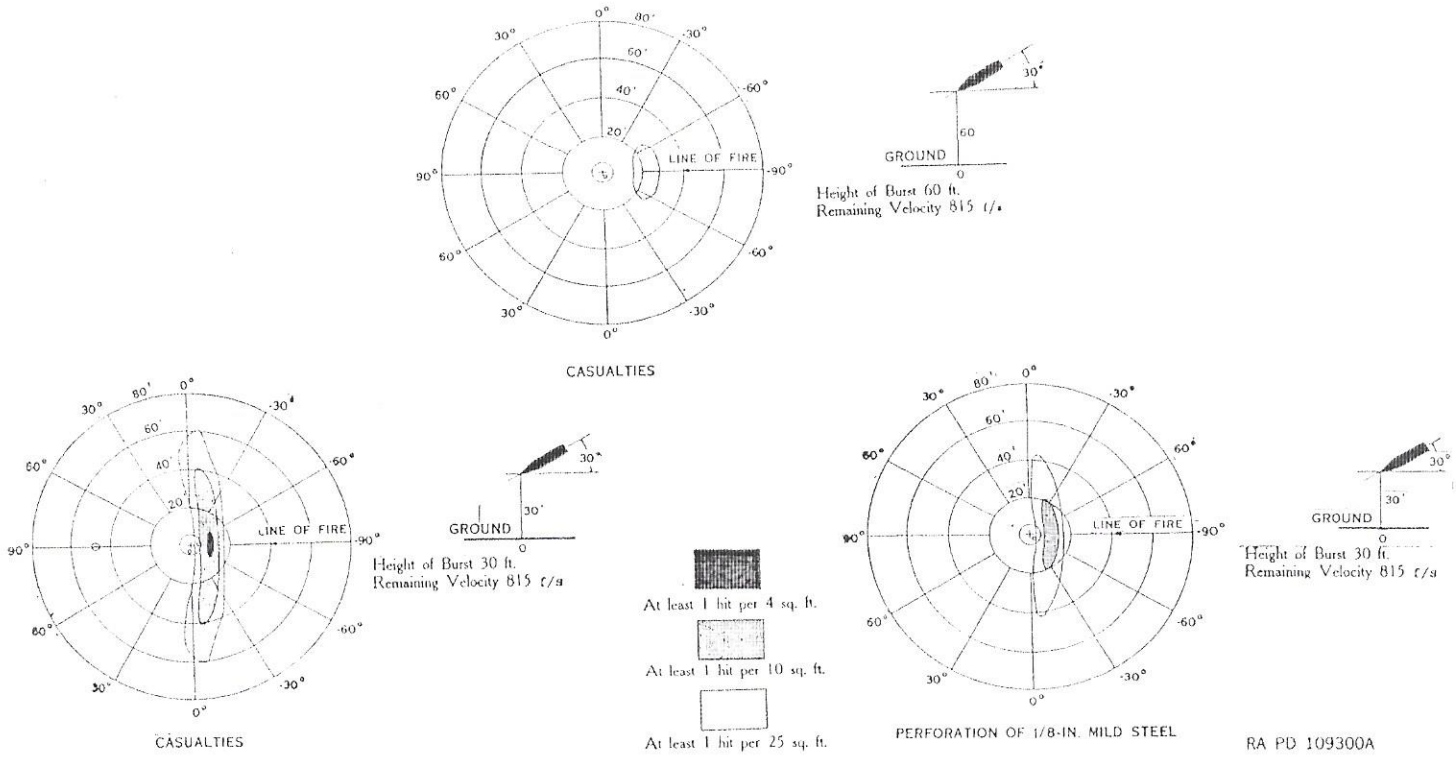


Figure 71. Damage pattern—76-mm HE shell, M42A1.

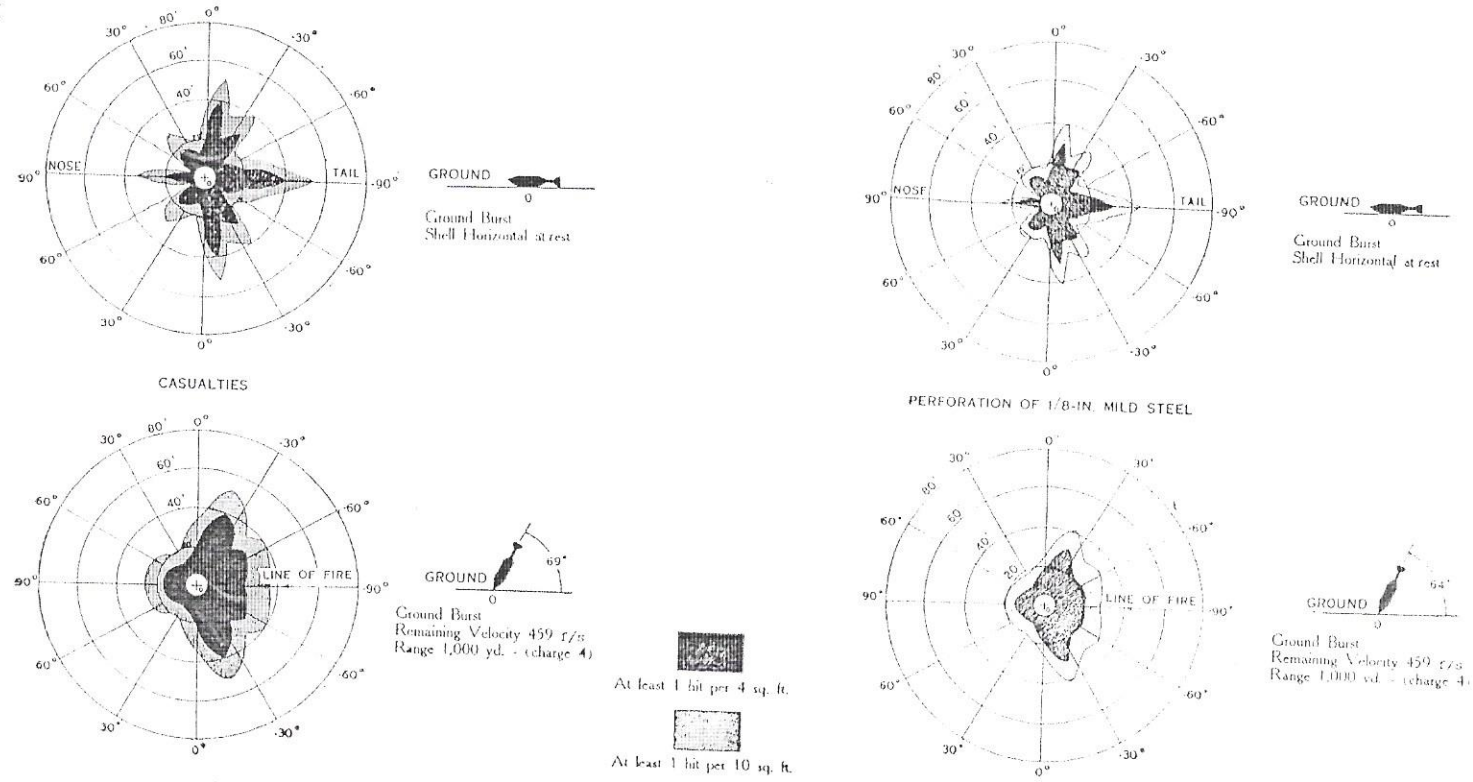


Figure 72. Damage pattern—81-mm HE shell, M56.

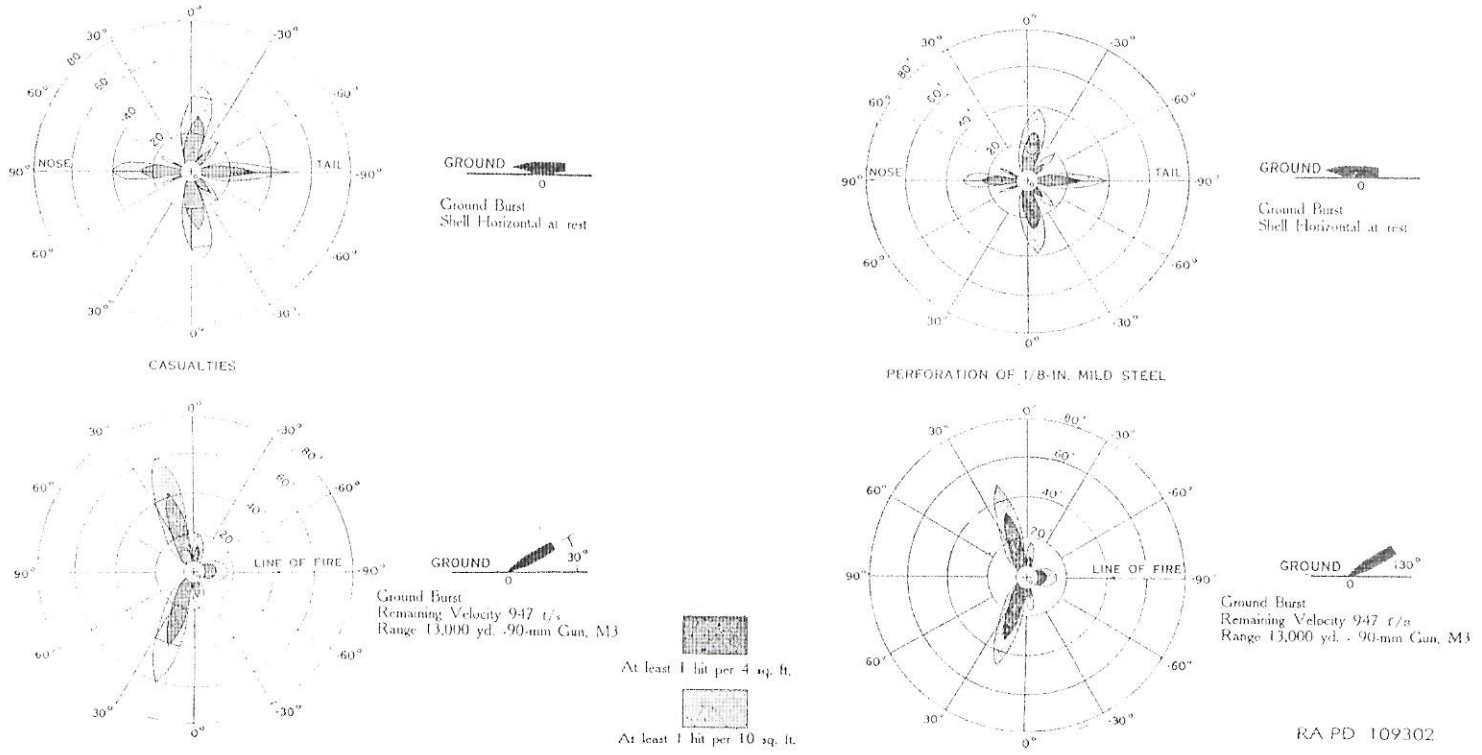


Figure 73. Damage pattern—90-mm HE shell, M71.

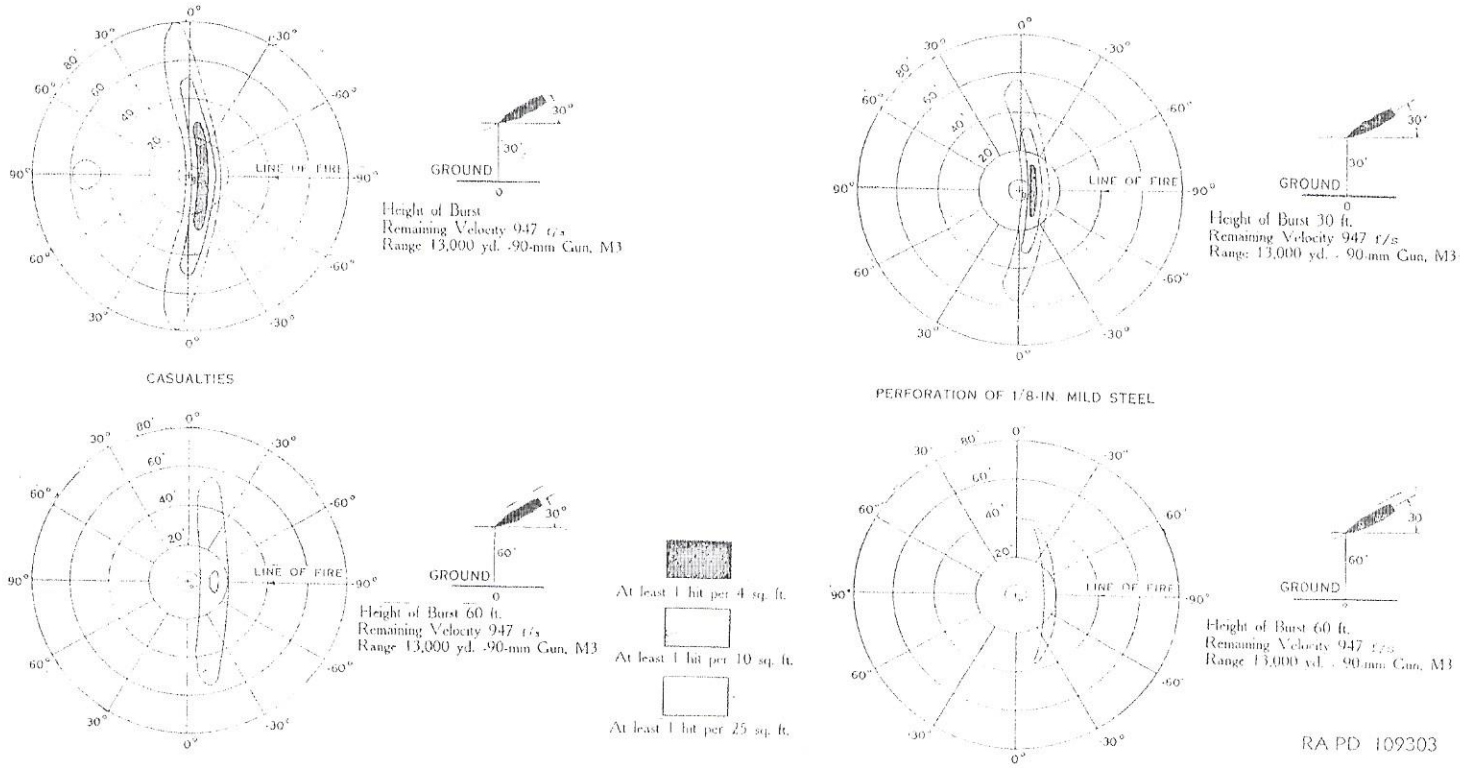
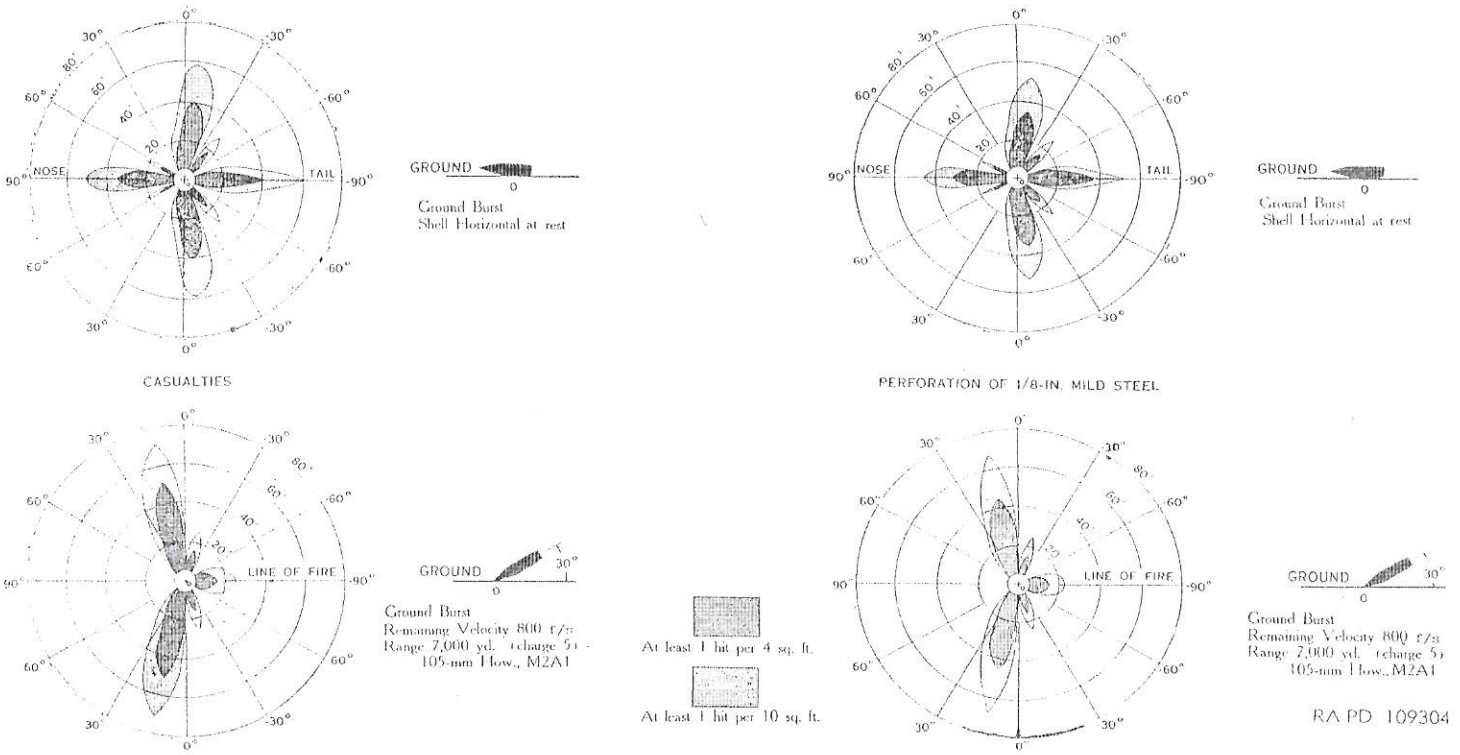
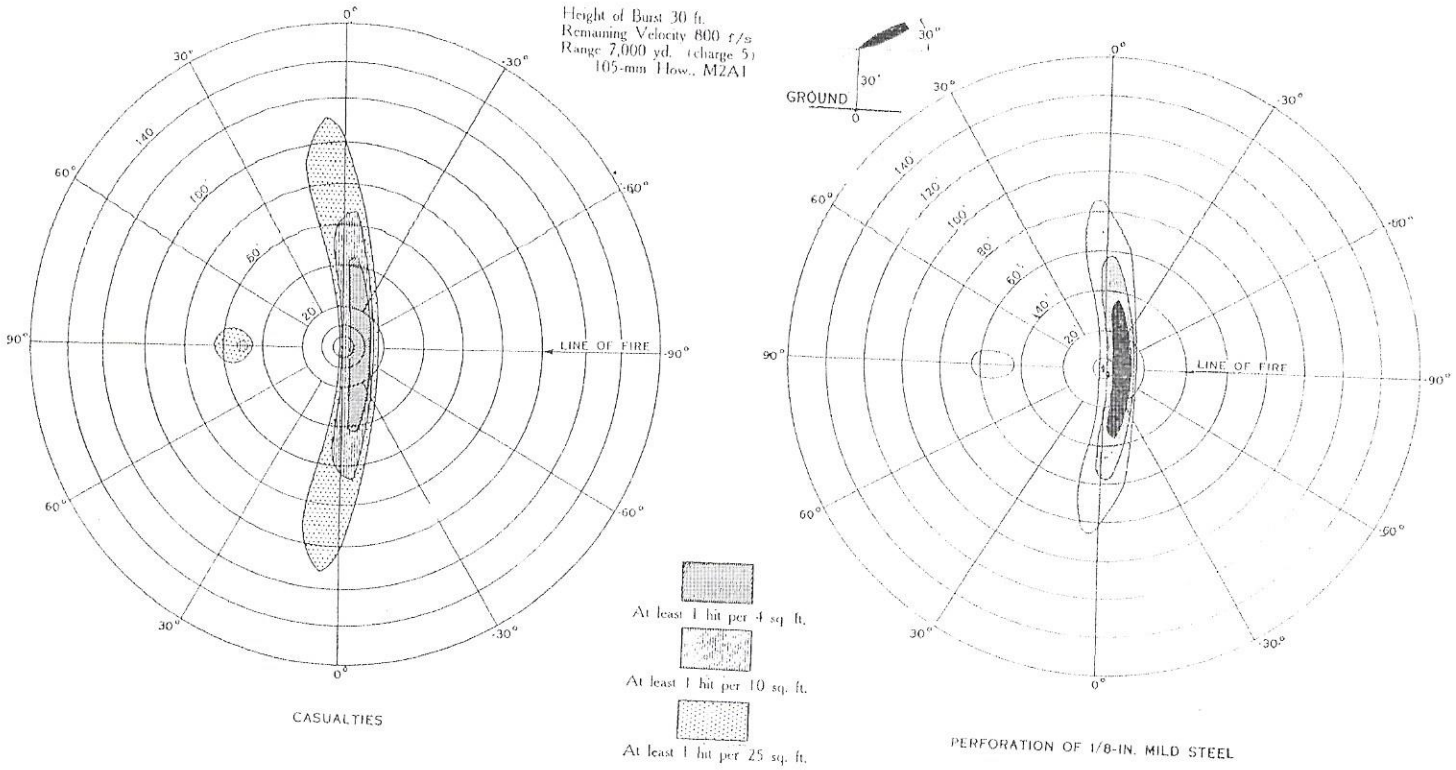


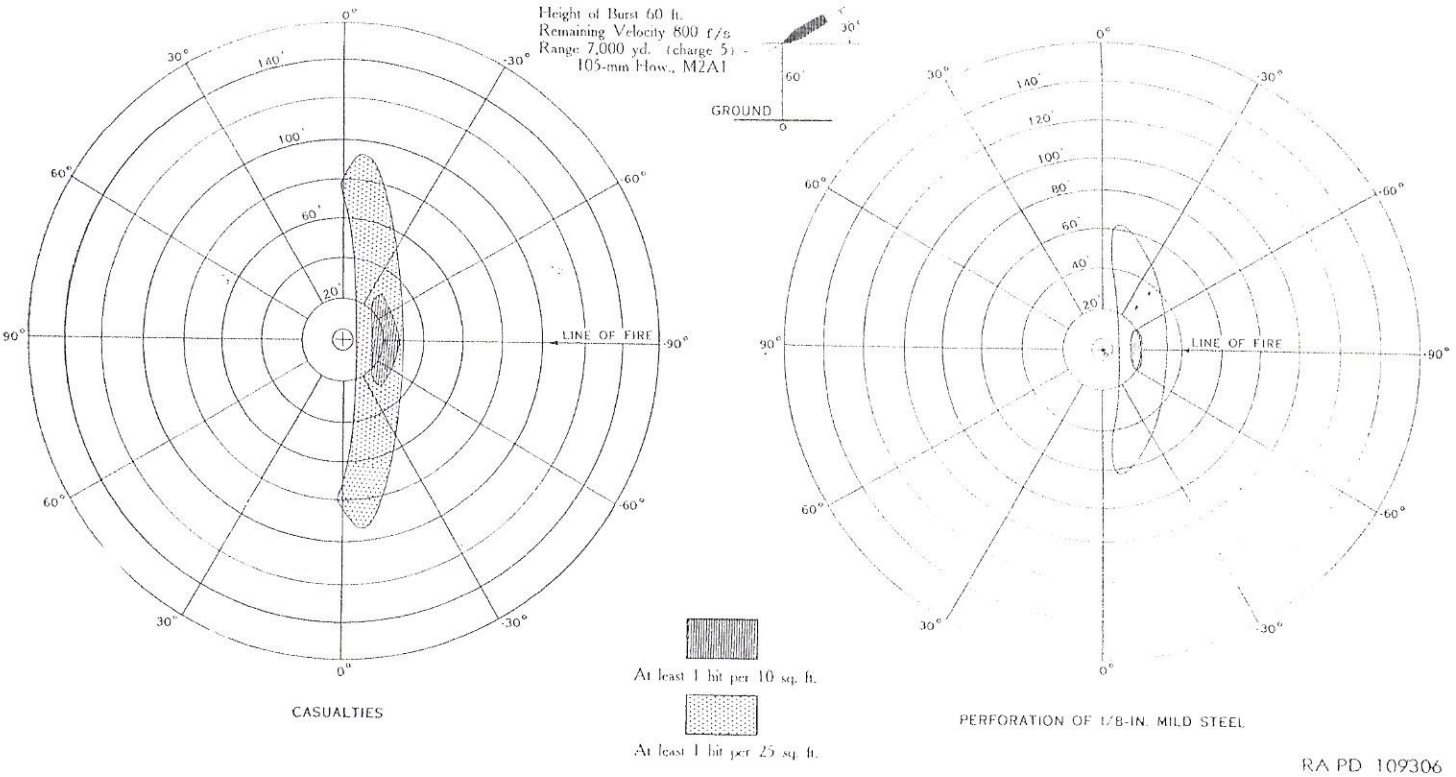
Figure 71. Damage pattern—90-mm HE shell, M71.





RA PD 109305

Figure 76. Damage pattern—105-mm HE shell, M1.



RA PD 109306

Figure 77. Damage pattern—105-mm HE shell, M1.

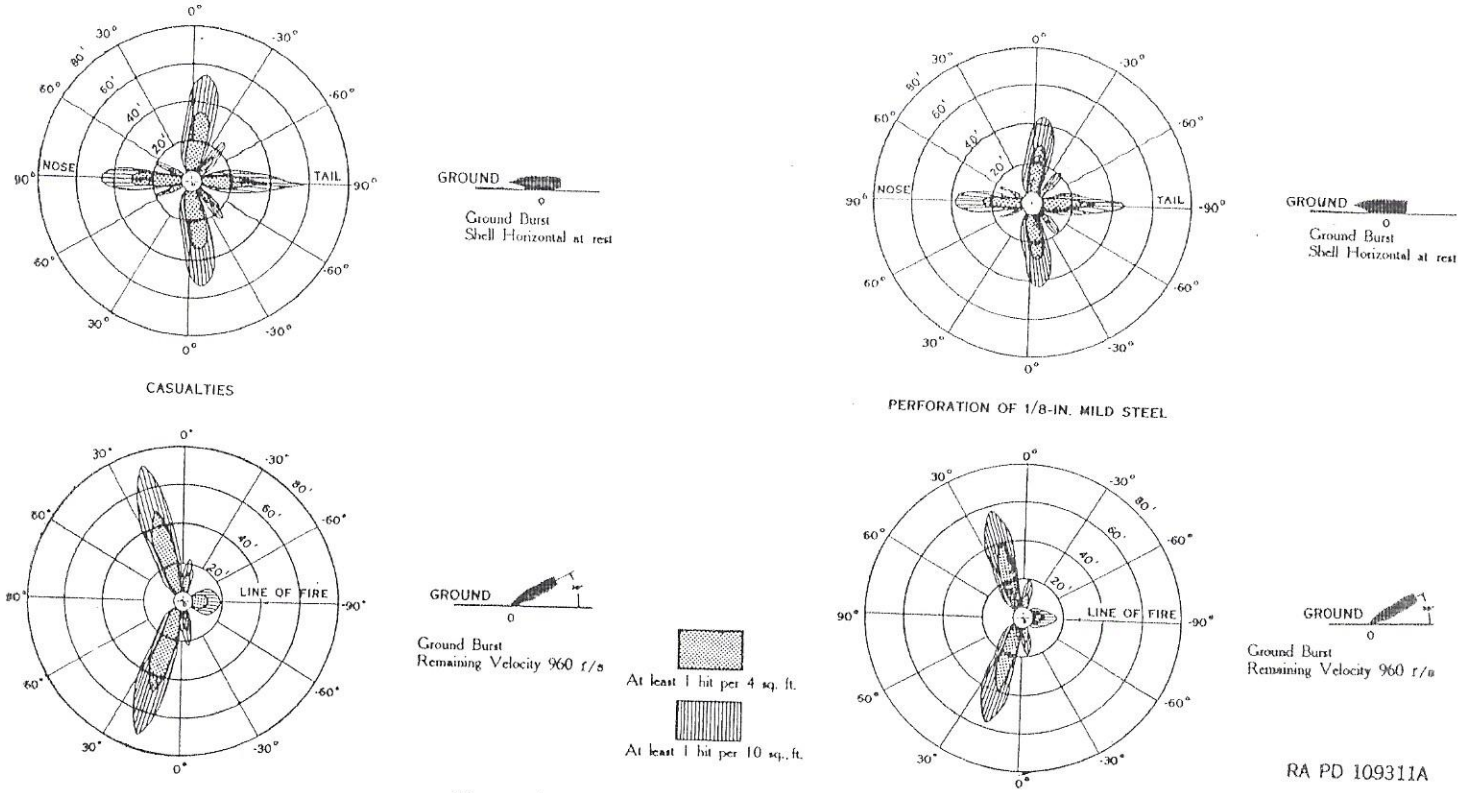


Figure 78. Damage pattern—120-mm HE shell, M75.

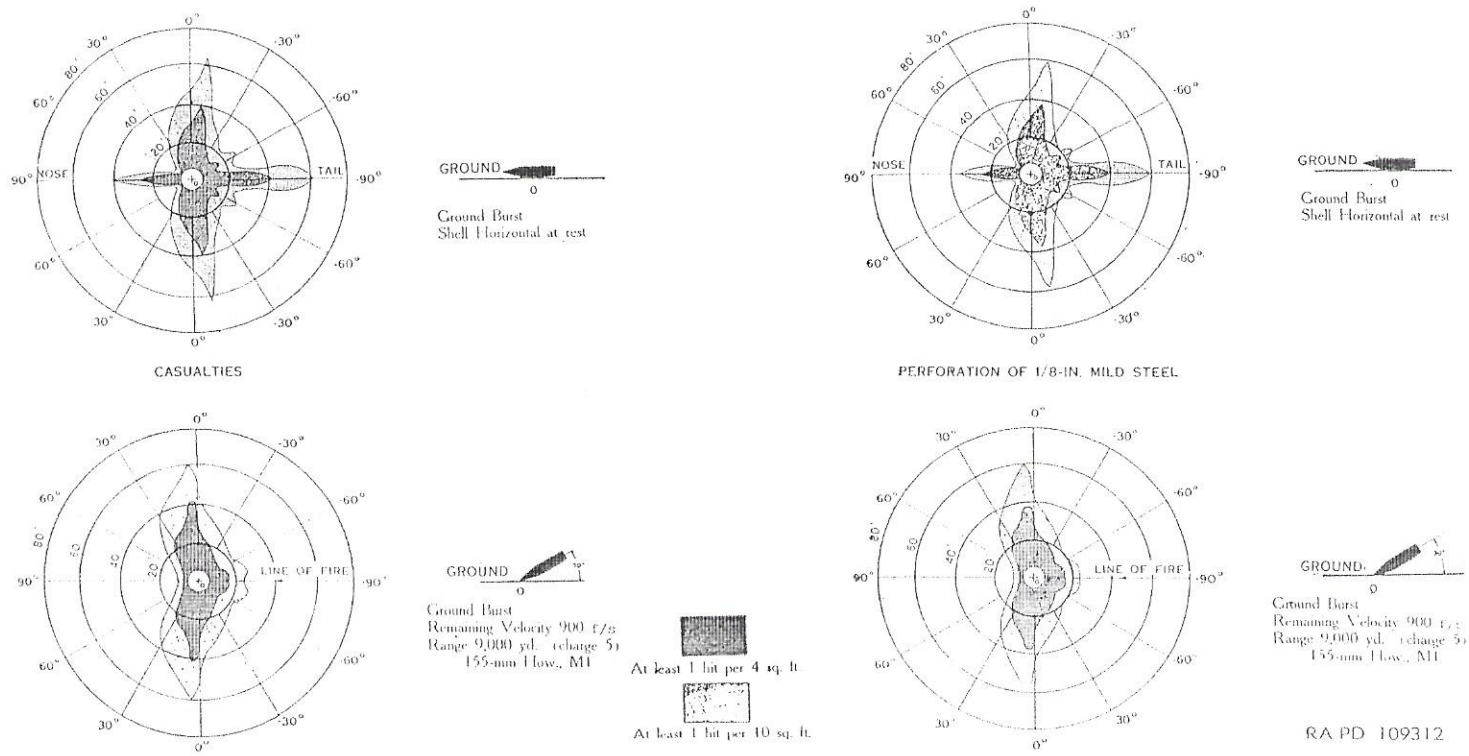


Figure 79. Damage pattern—155-mm HE shell, M107.

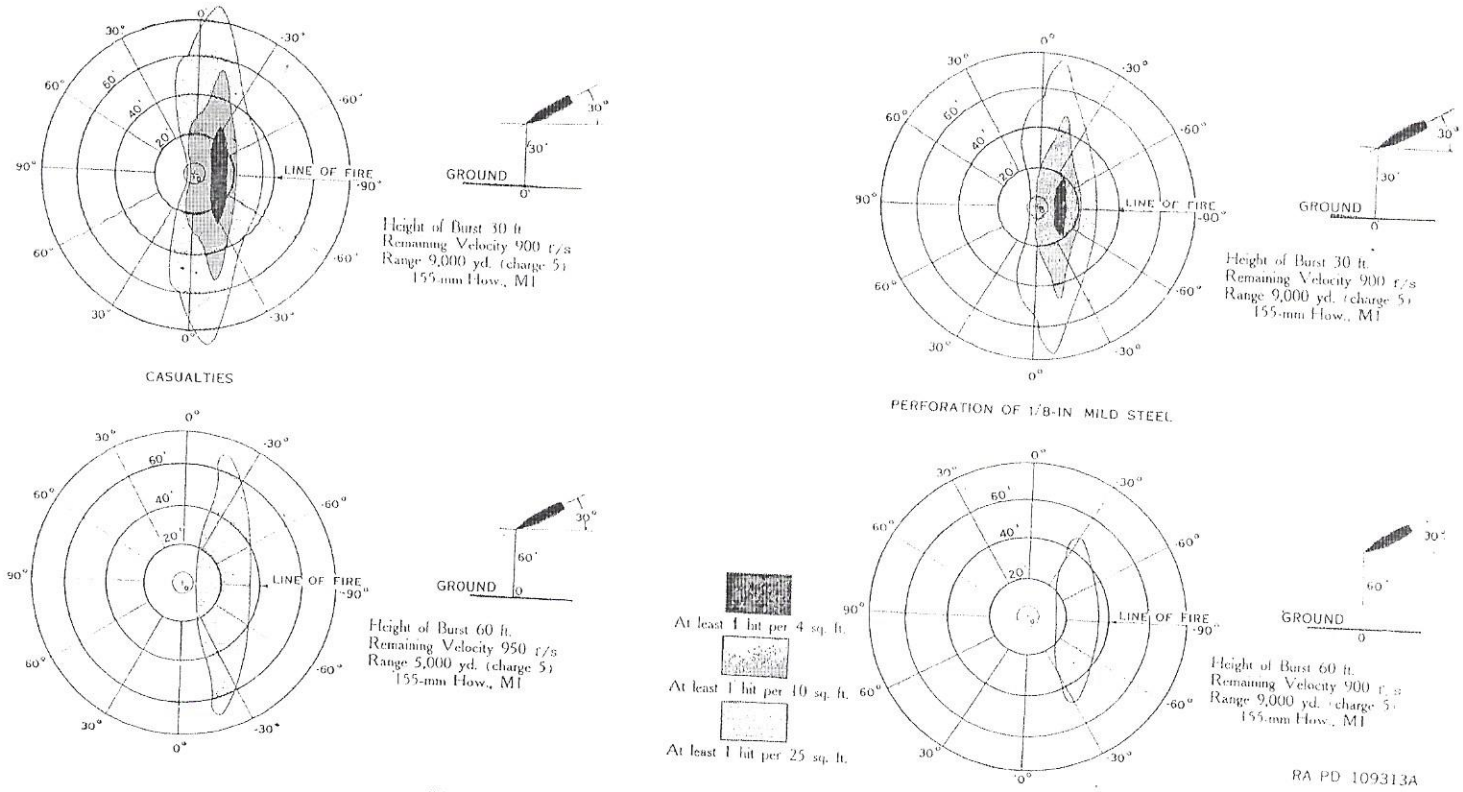


Figure 80. Damage pattern—155-mm HE shell, M107.

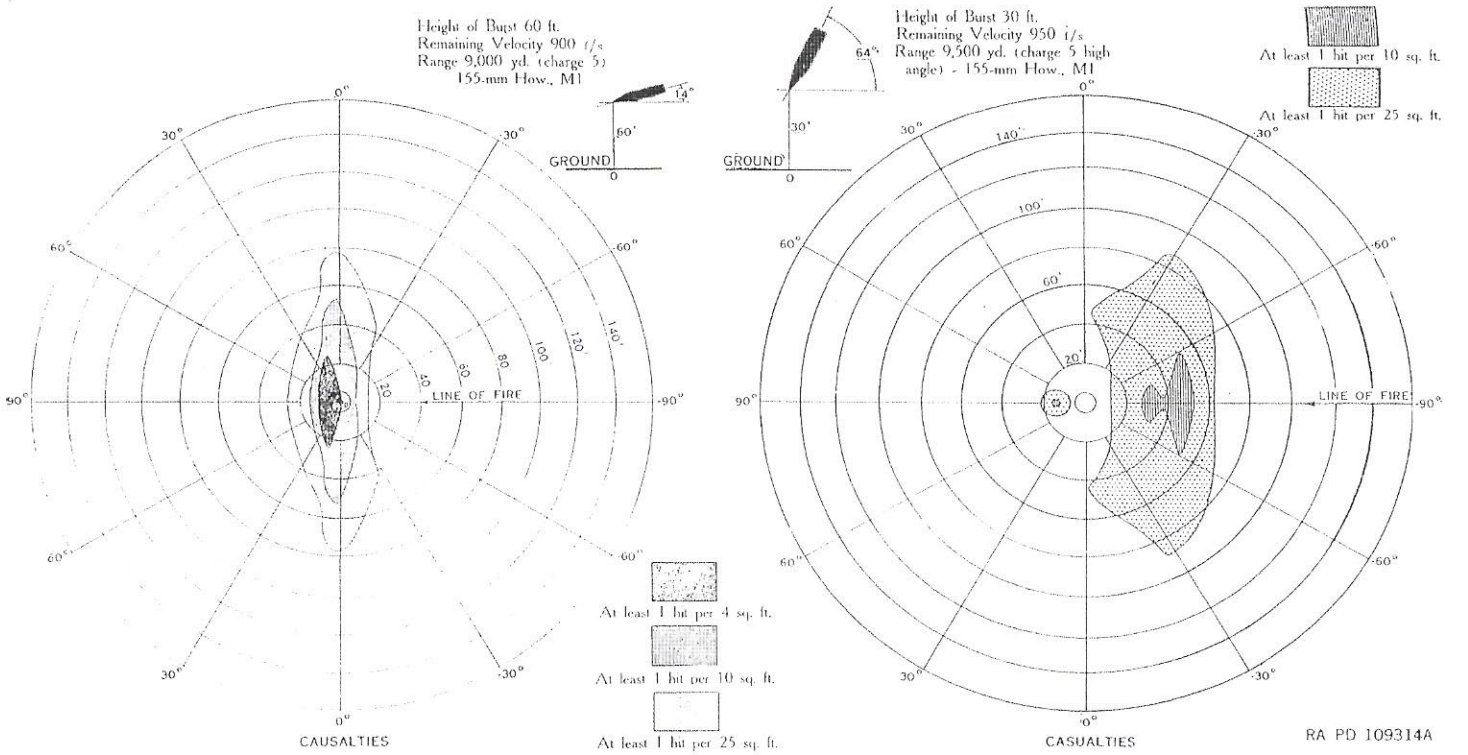


Figure 81. Damage pattern—155-mm HE shell, M107.

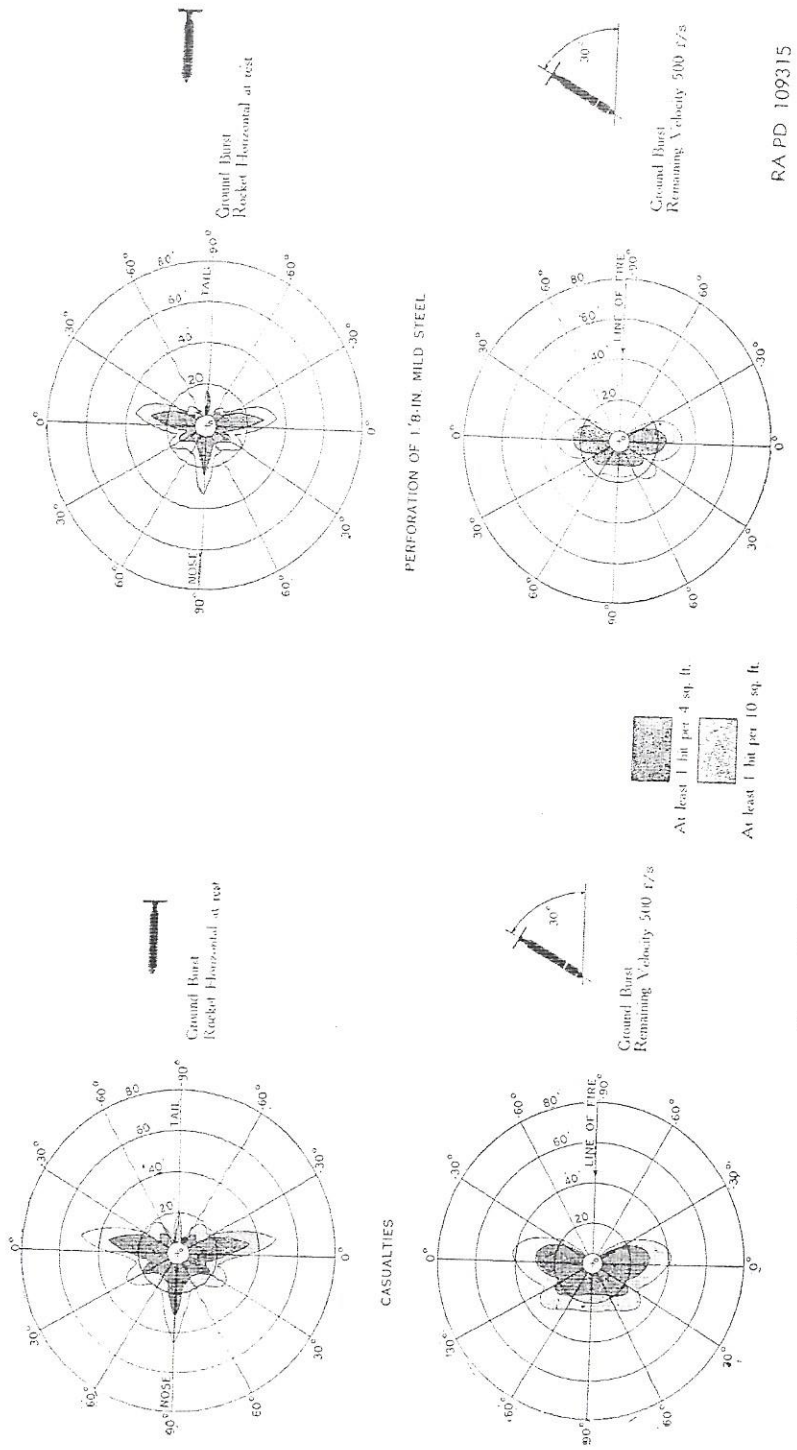


Figure 82. Damage pattern—4.5-in. HE rocket shell, T22.

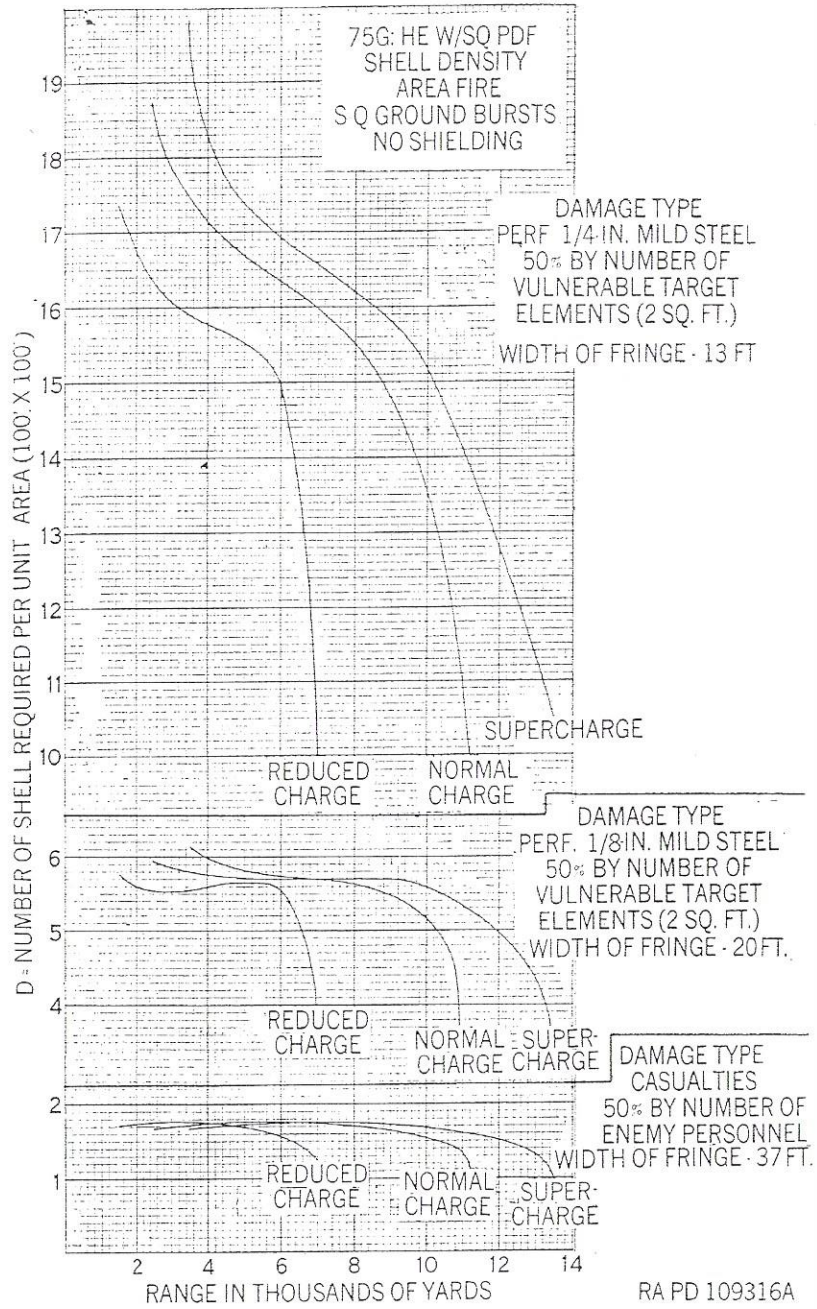


Figure 83. Shell density in area fire SQ ground burst—75-mm gun M3 and HE shell M48.

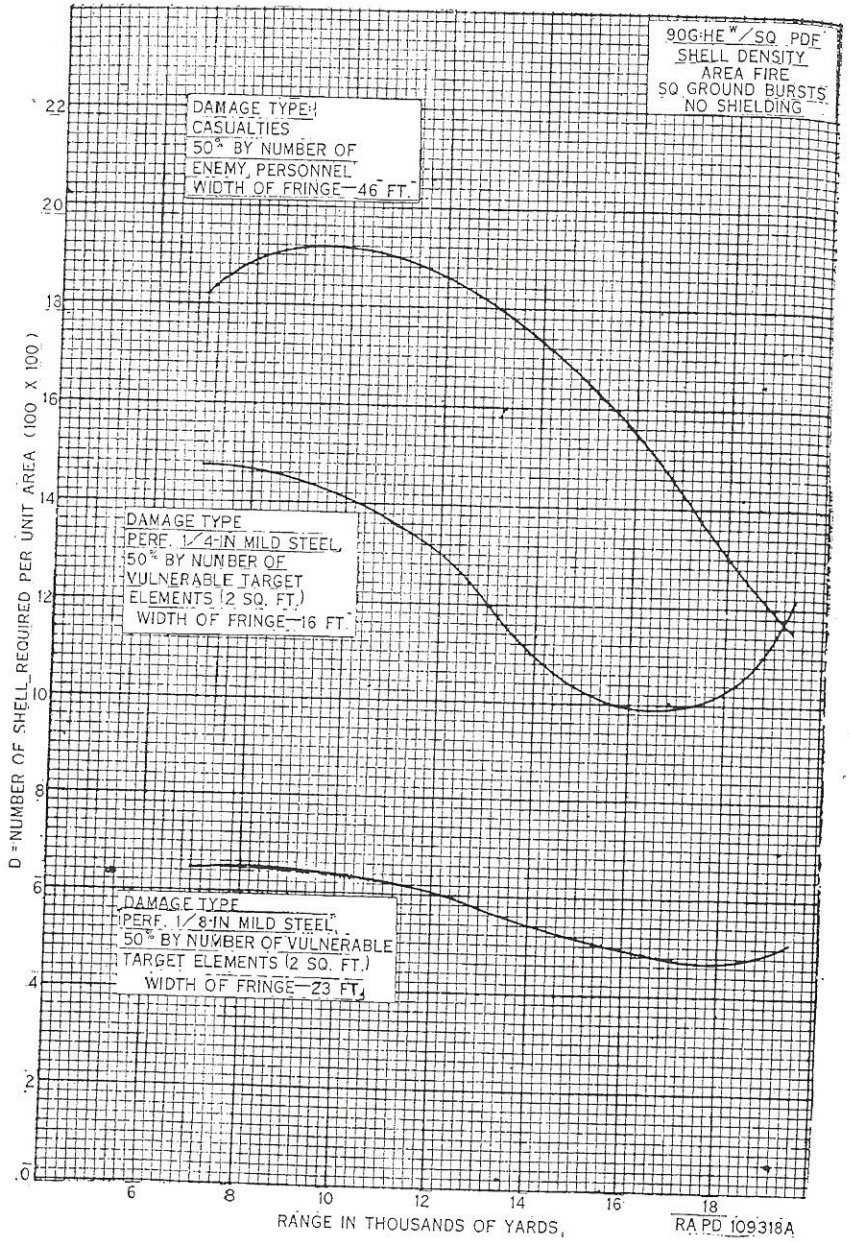


Figure 84. Shell density in area fire SQ ground burst—90-mm HE shell M 71 and 90-mm gun M1, M1A1, M2 or M3.

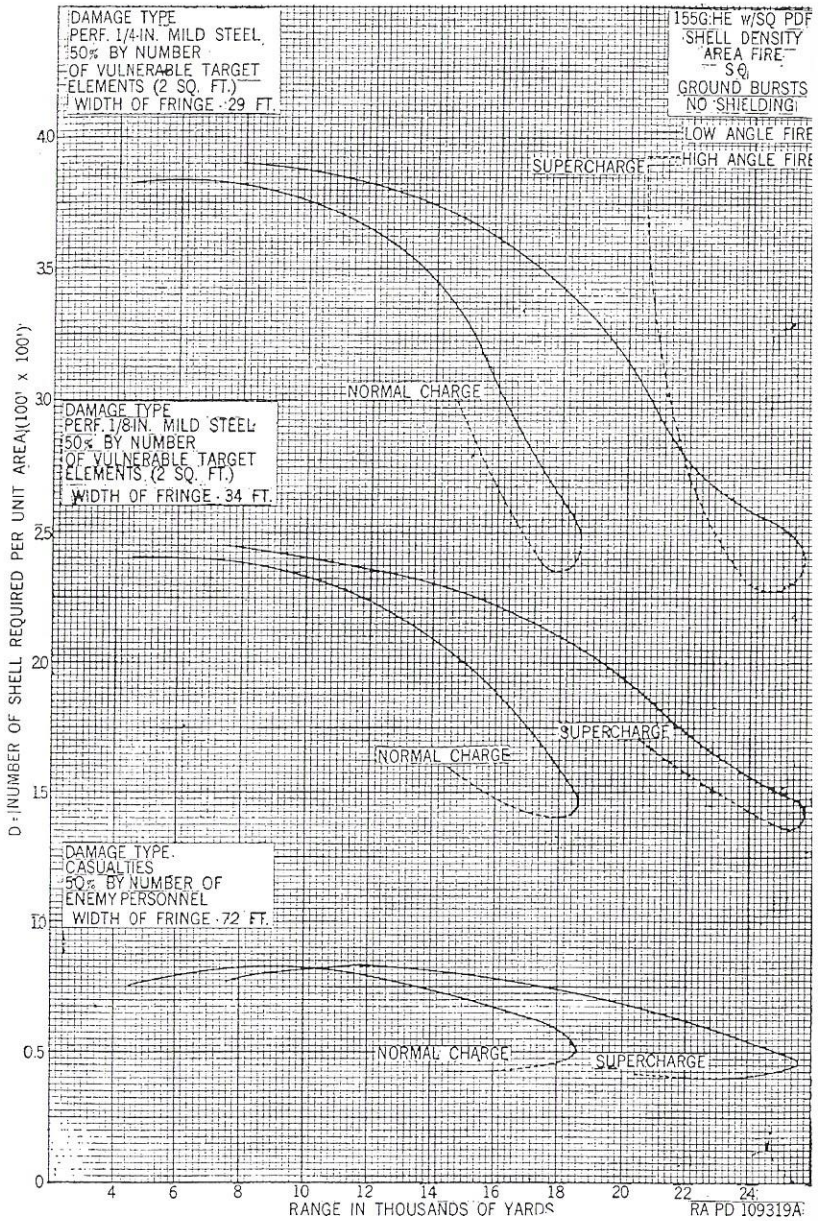


Figure 85. Shell density in area fire SQ ground burst—155-mm HE shell M101 and 155-mm gun M2.

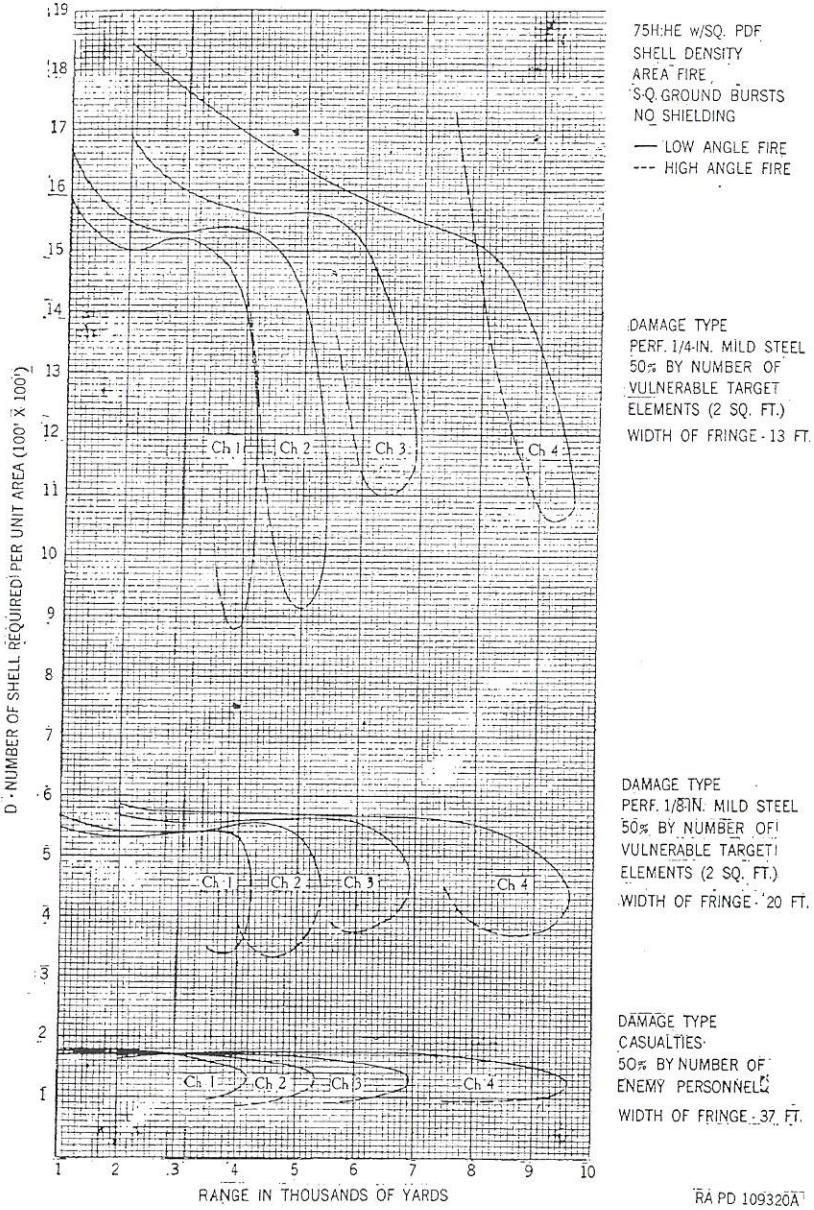


Figure 86. Shell density in area fire SQ ground burst—75-mm HE shell M48 and 75-mm how M1A1, M2 or M3.

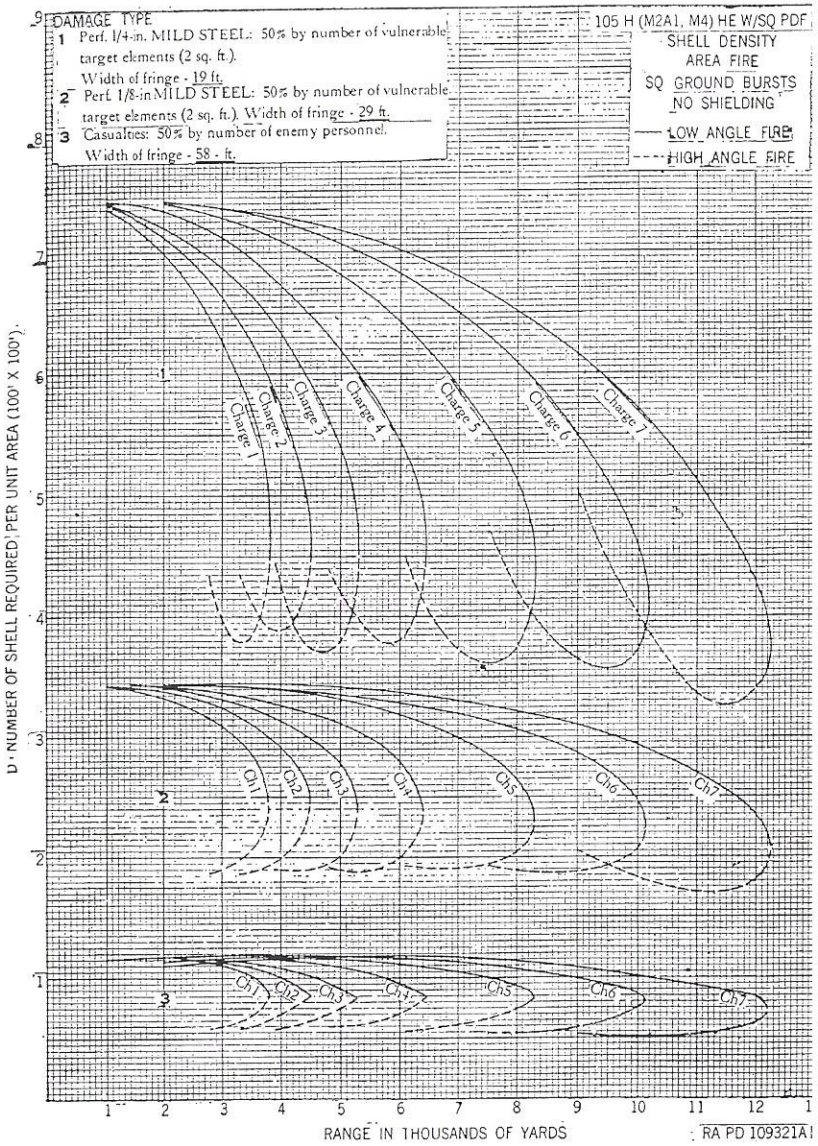


Figure 87. Shell density in area fire SQ ground burst—105-mm HE shell M1 an 105-mm how M2A1 or M4.

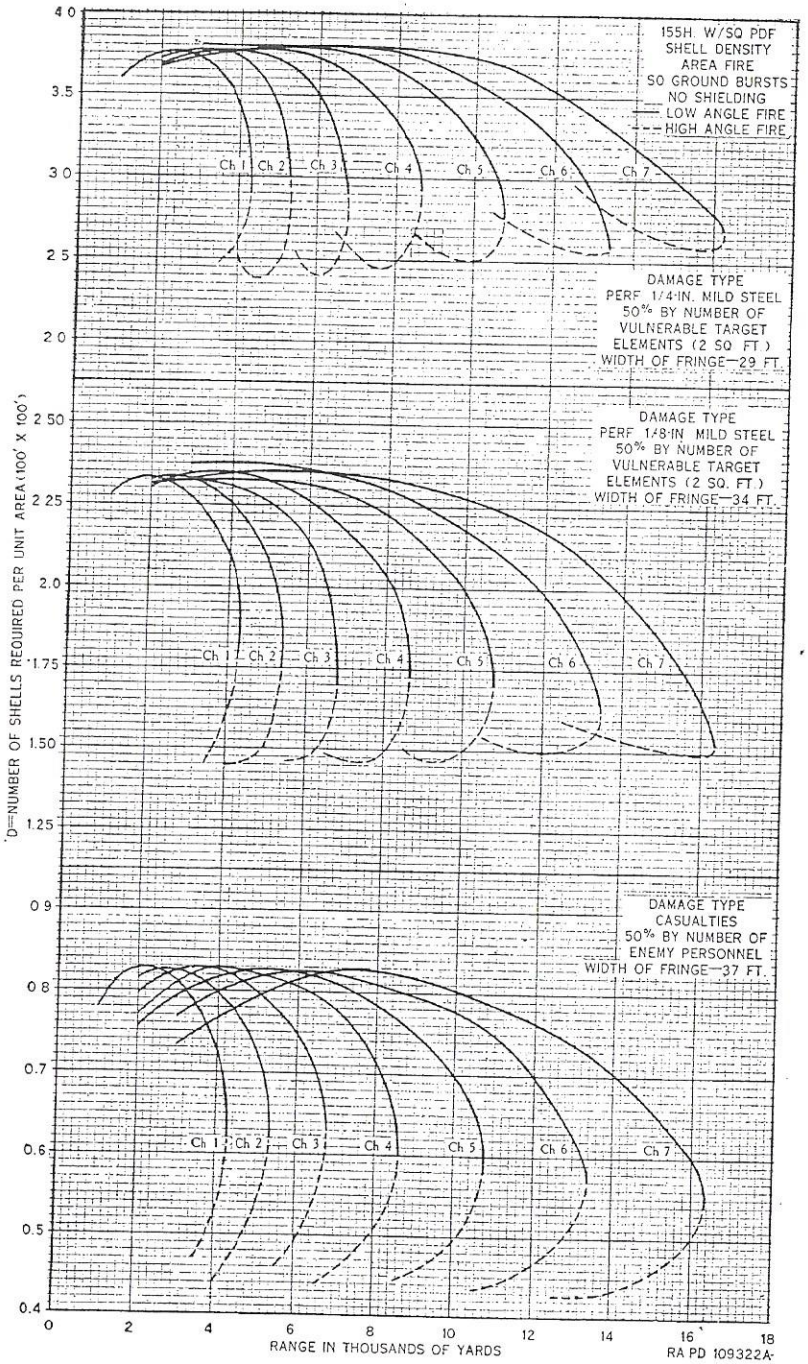


Figure 88. Shell density in area fire SQ ground burst—155-mm HE shell M107 and 155-mm how M1.

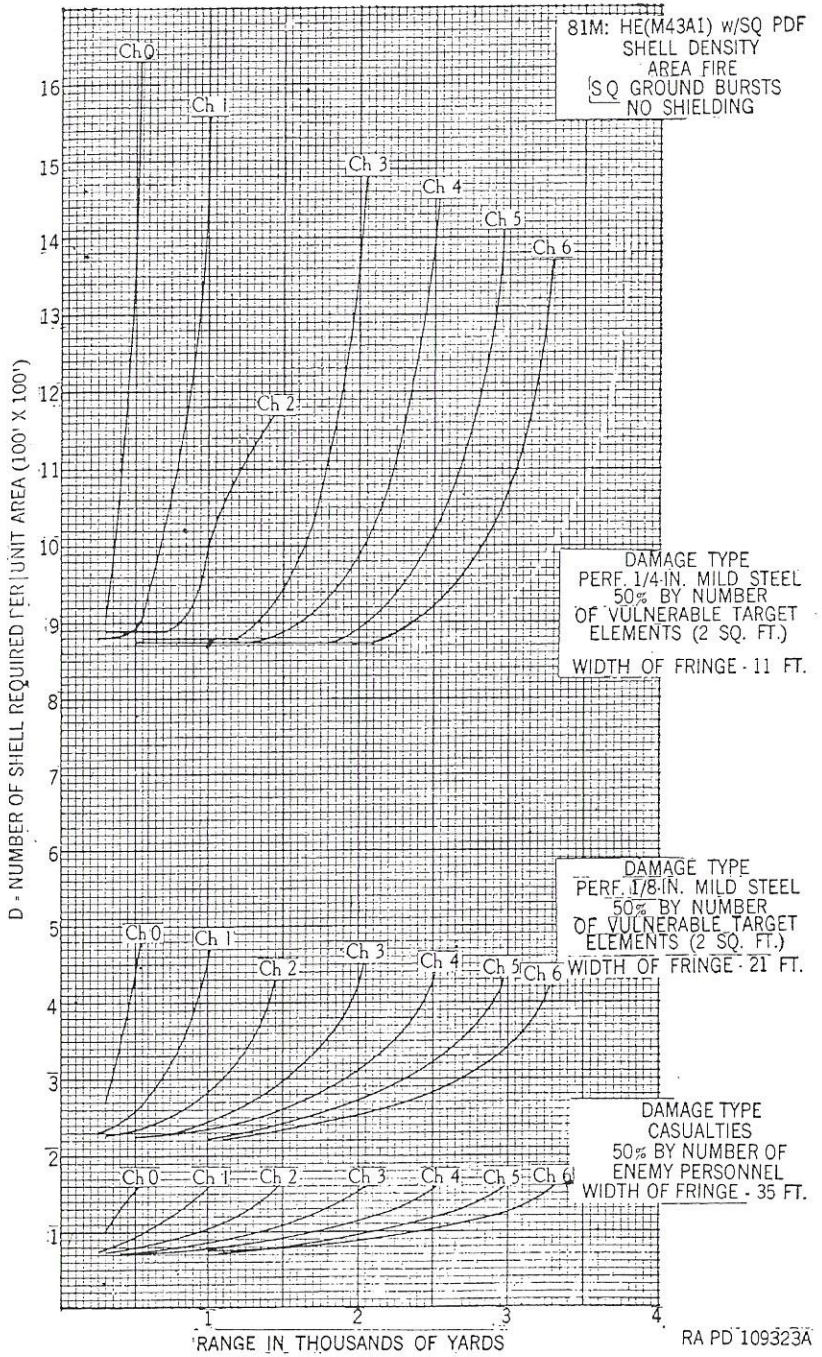


Figure 89. Shell density in area fire SQ ground burst—81-mm HE mortar shell M43A1 and 81-mm mortar M1.

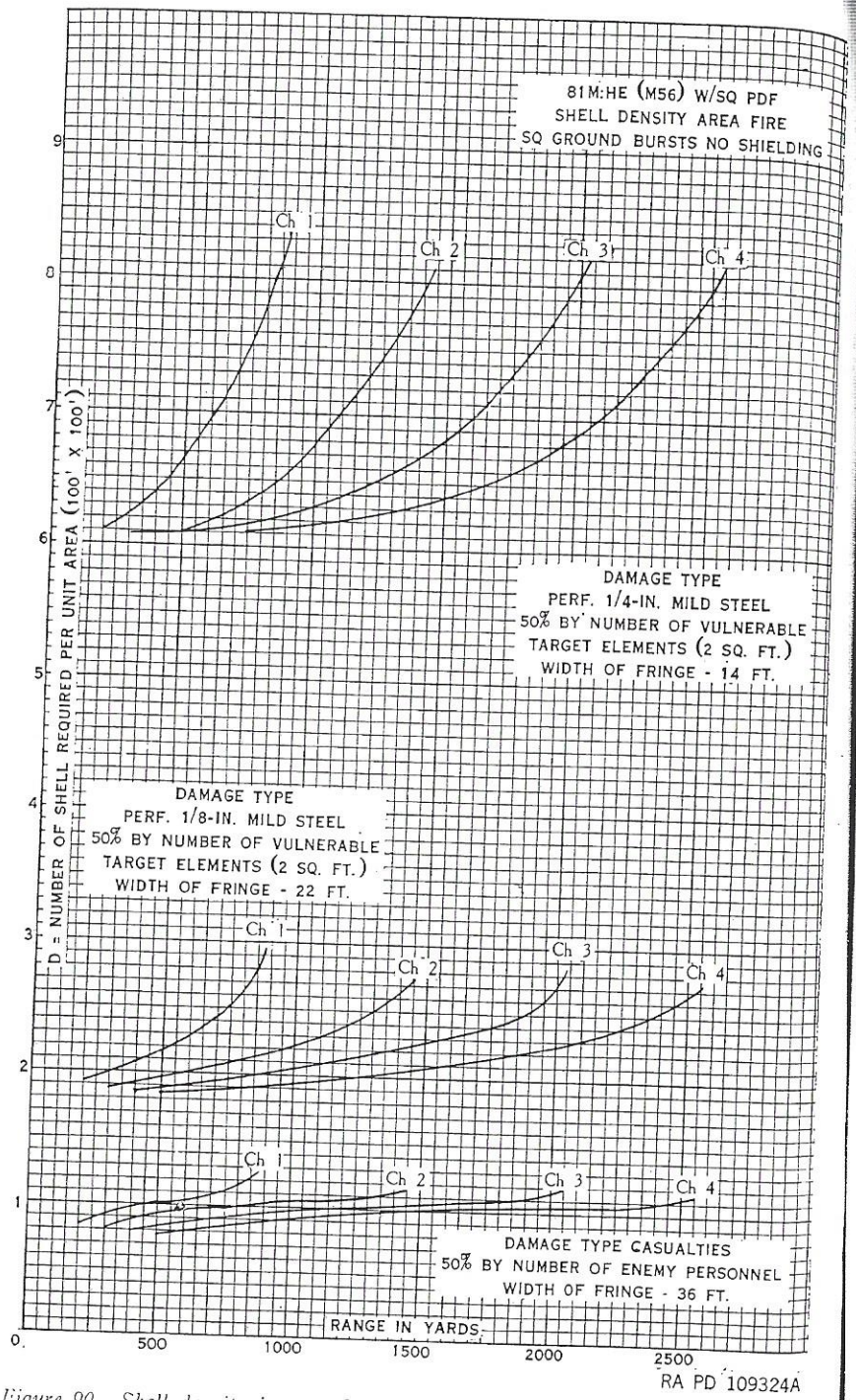


Figure 90. Shell density in area fire SQ ground burst—81-mm HE mortar shell M56 and 81-mm mortar M1.

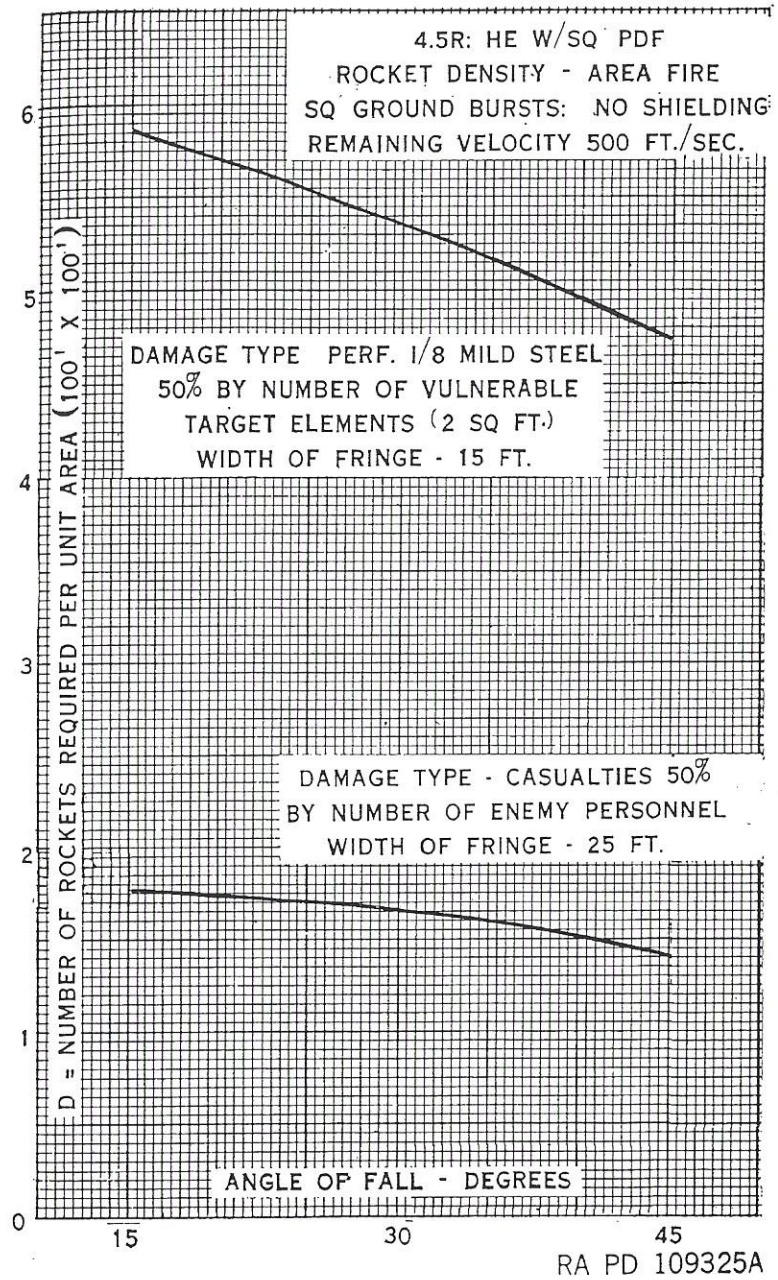


Figure 91. Shell density in area fire SQ ground burst—4.5-in. HE rocket T22.

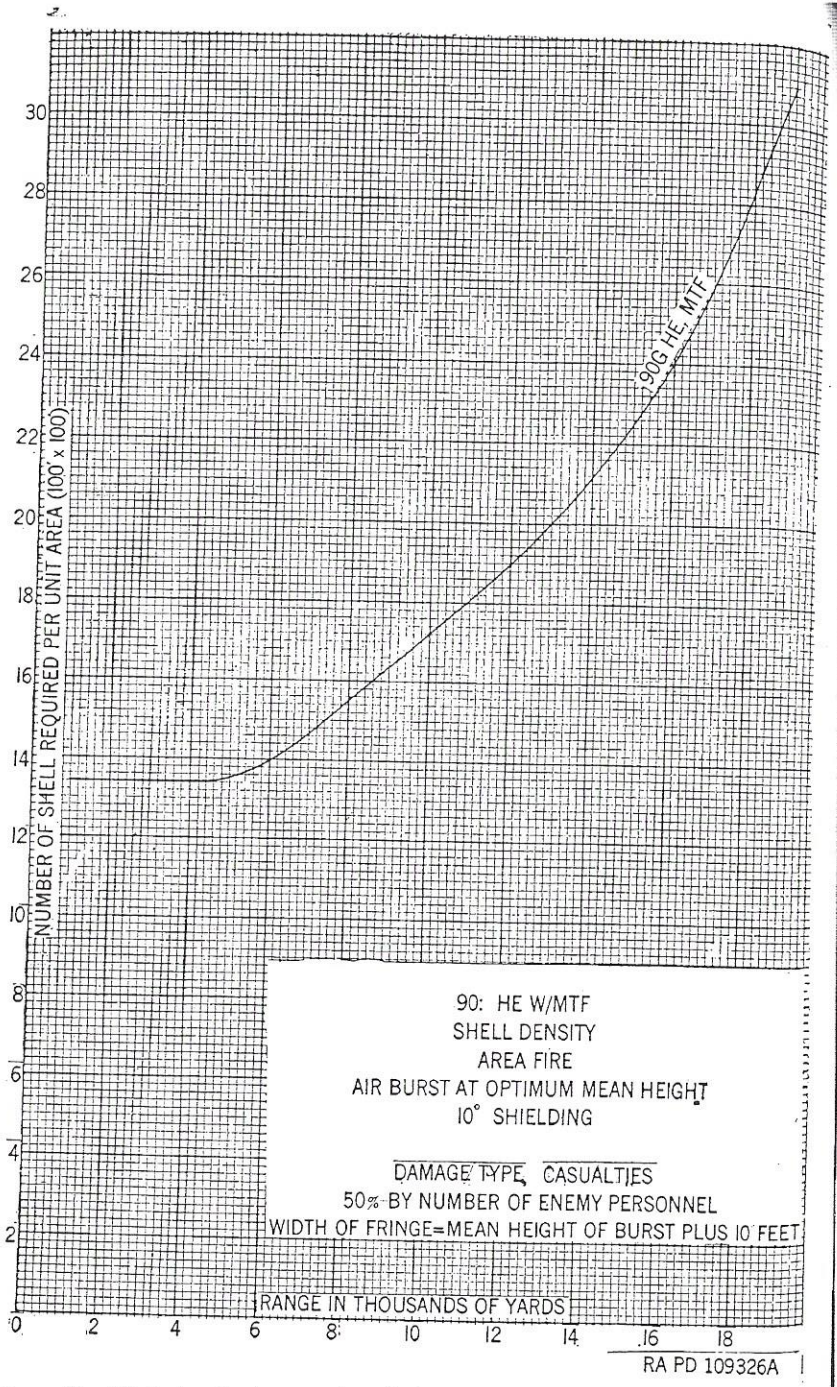


Figure 92. Shell density in area fire air burst—90-mm gun M1, M1A1, M2 and M3; HE shell w/mechanical time fuze.

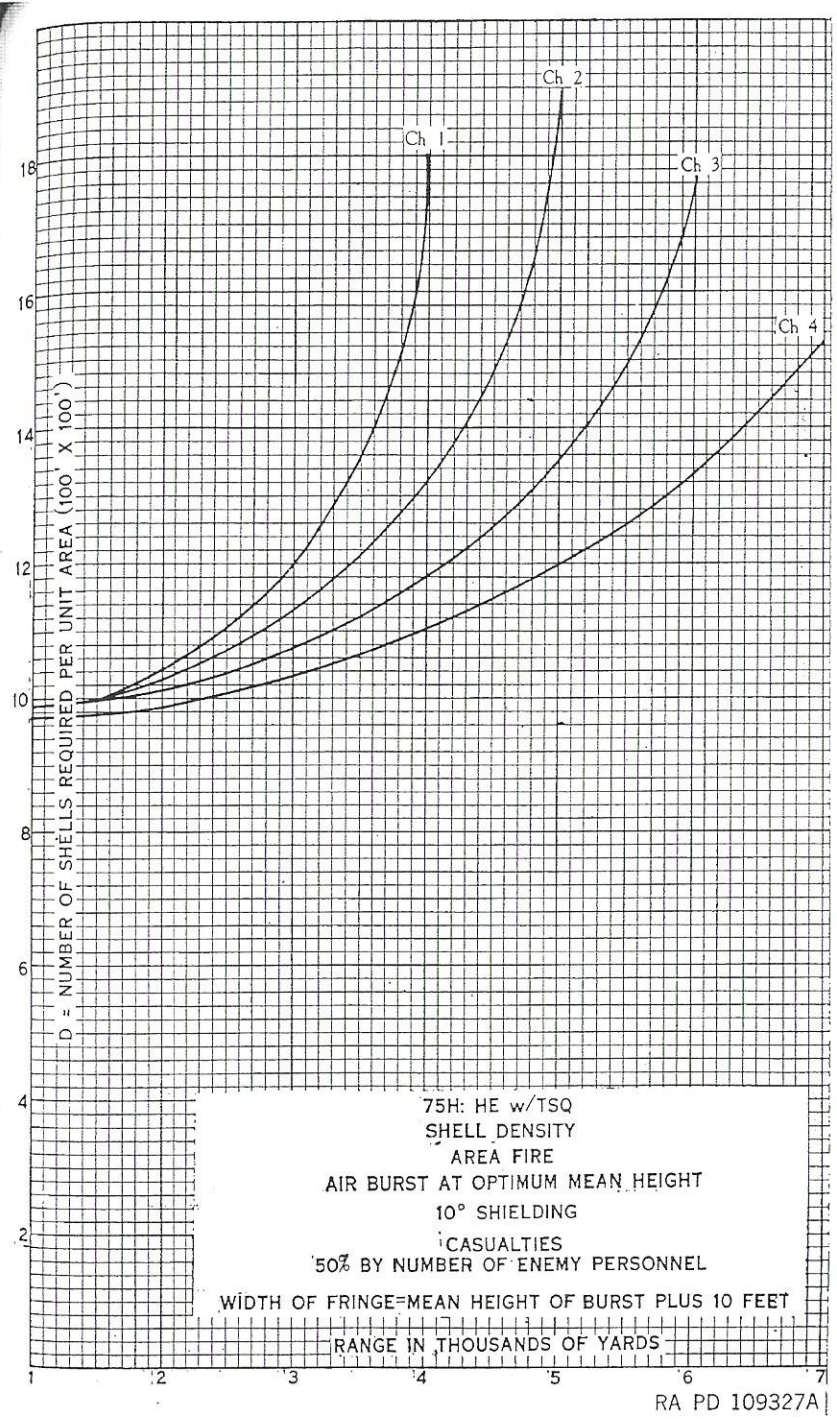


Figure 93. Shell density in area fire air burst—75-mm how M1A1, M2 or M3; HE shell w/TSQ fuze.

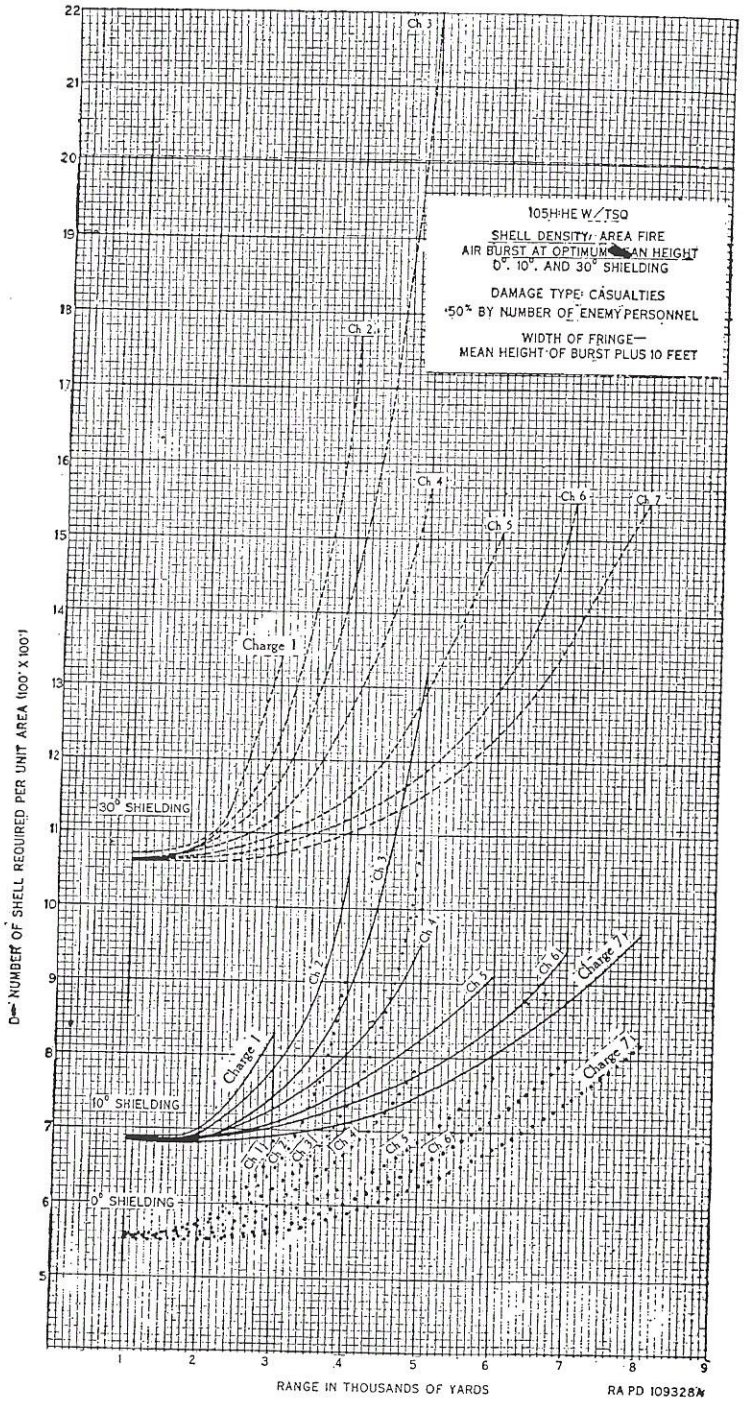


Figure 94. Shell density in area fire air burst—105-mm how M2A1 or M4; HE shell w/TSQ fuze.

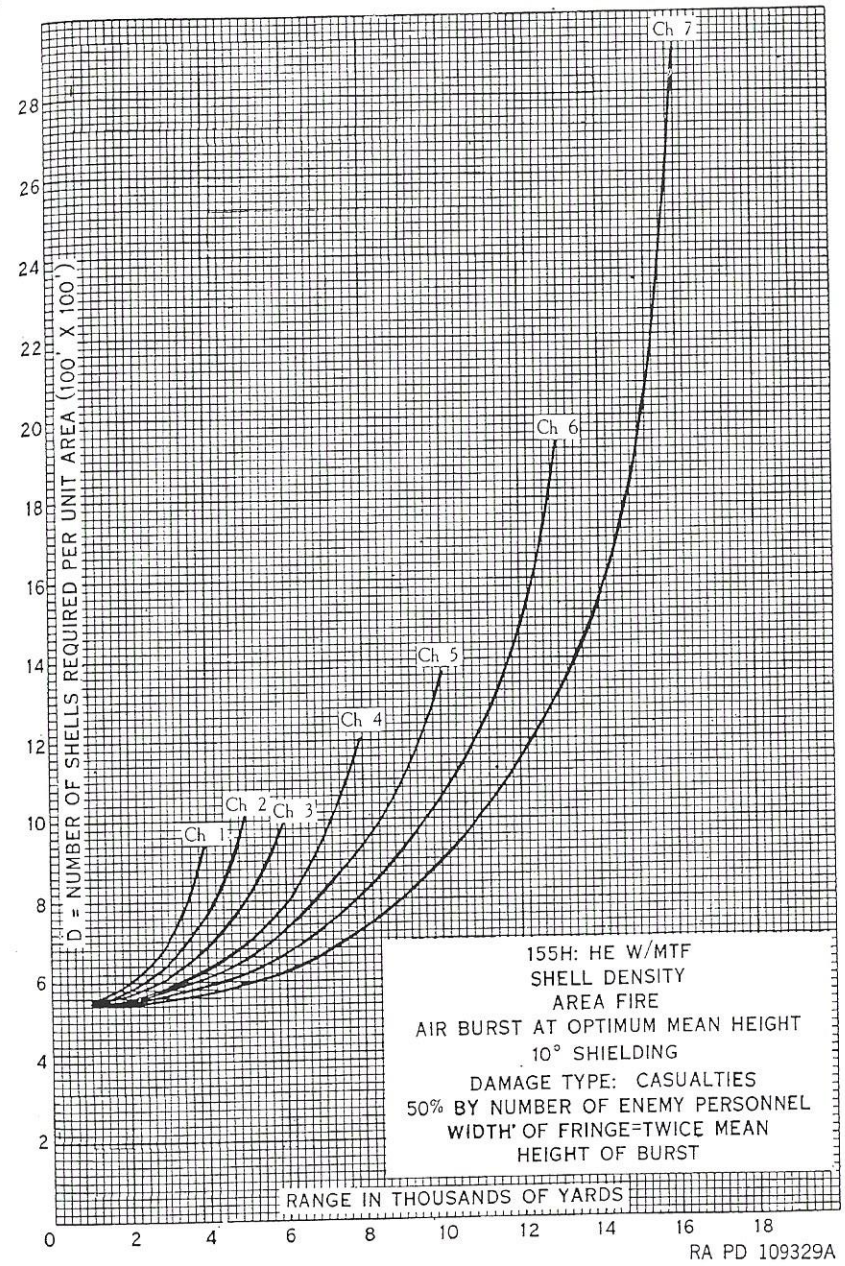


Figure 95. Shell density in area fire air burst—155-mm how M1 HE shell w/mechanical time fuze.

Section II. RICOCHET DATA

65. General

a. Scope. This section presents a series of tables which give ricochet data on artillery shells.

b. Ricochet Trajectory. Figure 96, ricochet trajectory, shows the position of the burst with respect to the impact after ricochet from level ground when a point detonating delay fuze is used. The quantities *angle of fall, angle of recovery,* distance from *impact to burst, height of burst,* and *probable error in height of burst* are tabulated against range for several combinations of gun and ammunition in tables XL to XLVIII. The tables apply not only to the gun and ammunition listed but also to any gun and charge firing the ammunition with the tabulated muzzle velocity and any fuze of the same standard contour with the tabulated delay time. Ricochets ordinarily are not expected at longer ranges (larger angles of fall) than those tabulated. The angle and velocity of recovery and consequent position of burst depend on the slope of the soil, the soil density, and other factors. These tables are based on data gathered on level soil which is a sand clay mixture, well integrated, and believed to be a general average of soil hardness. The probable error in height of burst will depend on the uniformity of the surface in the impact area.

Note. Tables XL to XLVIII contain data for the listed fuze delay times only. These same fuzes have other delay times than those listed. However, the delay time is indicated on each fuze as part of the fuze nomenclature.

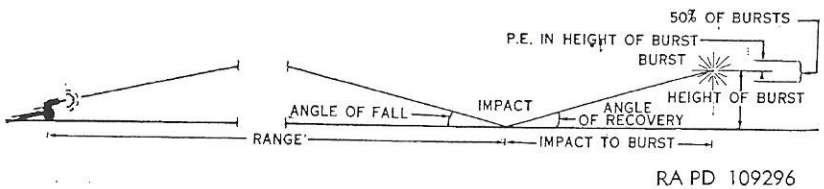


Figure 96. Ricochet trajectory.

Table XL. Ricochet Data: 75-mm HE Shell M48 and 75-mm Howitzer and 75-mm Gun

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burst
	yd	mils	mils	yd	ft	ft
Howitzer, 75-mm, M1A1 M2 and M3						
Charge 1						
MV 700 f/s	1,000	109	155	26	12	2
Fuze, PD, M48A1,	2,000	242	265	17	14	3
M48A2 and M51A4	3,000	415	315	7	7	2
(0.15 sec. delay)						
Charge 2						
MV 810 f/s	1,000	82	120	32	12	2
Fuze, PD, M48A1,	2,000	178	220	24	16	3
M48A2 and M51A4	3,000	295	295	15	14	3
(0.15 sec. delay)						
Charge 3						
MV 950 f/s	1,000	58	90	40	11	2
Fuze, PD, M48A1,	2,000	127	175	33	21	4
M48A2 and M51A4	3,000	208	245	25	18	4
(0.15 sec. delay)	4,000	305	295	17	15	4
	5,000	425	315	8	8	3
Charge 4						
MV 1,250 f/s	1,000	38	60	51	11	2
Fuze, PD, M48A1,	2,000	86	125	42	16	3
M48A2 and M51A4	3,000	142	190	35	20	4
(0.15 sec. delay)	4,000	206	245	28	21	4
	5,000	279	285	21	18	4
	6,000	363	310	14	14	4
Gun, 75-mm, M3, M6 and M17						
Reduced charge						
MV 960 f/s	1,000	59	90	40	11	2
Fuze, PD, M48A1,	2,000	126	170	33	17	3
M48A2 and M51A4	3,000	206	245	25	18	4
(0.15 sec. delay)	4,000	301	295	17	16	4
Normal charge						
MV 1,520 f/s	1,000	26	45	62	8	2
Fuze, PD, M48A1,	2,000	65	100	50	15	3
M48A2 and M51A4	3,000	115	160	41	19	4
(0.15 sec. delay)	4,000	174	220	33	22	5
	5,000	240	265	26	21	5
	6,000	313	300	19	17	4
	7,000	394	315	13	12	4
Super charge						
MV 1,980 f/s	1,000	13	25	28	2	0
Fuze, PD, M48,	2,000	36	60	23	4	1
M48A2 and M51A4	3,000	70	105	19	6	1
(0.05 sec. delay)	4,000	116	160	14	7	1
	5,000	171	215	12	8	2
	6,000	234	260	9	7	2
	7,000	303	295	7	6	2
	8,000	378	315	5	4	1

Table XLI. Ricochet Data: 76-mm HE Shell M42A1 and 76-mm Gun

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burst
	yd	mils	mils	yd	ft	ft
Gun, 76-mm, M1A1C, M1A2						
MV 2,700 f/s Fuze, PD, M48, M48A2 and M51A4 (0.05 sec. delay)	1,000	8	20	40	3	0
	2,000	20	35	33	4	1
	3,000	38	60	26	5	1
	4,000	65	100	21	6	1
	5,000	106	150	16	7	1
	6,000	163	210	12	7	2
	7,000	233	260	9	7	2
	8,000	315	300	6	6	1
	9,000	407	315	4	4	1

Table XLII. Ricochet Data: 90-mm HE Shell and 90-mm Gun

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burst
	yd	mils	mils	yd	ft	ft
Gun, 90-mm, M1, M1A1, M2, M3						
MV 2,700 f/s Fuze, PD, M48, M48A2 and M51A4 (0.05 sec. delay)	1,000	7	20	41	2	0
	2,000	17	30	36	3	1
	3,000	30	50	32	5	1
	4,000	47	75	28	6	1
	5,000	69	105	23	7	1
	6,000	98	140	19	8	2
	7,000	136	180	15	8	2
	8,000	187	230	12	8	2
	9,000	249	270	9	8	2
	10,000	314	300	7	6	2

Table XLIII. Ricochet Data: 105-mm HE Shell M1 and 105-mm Howitzer

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burst
	yd	mils	mils	yd	ft	ft
Howitzer, 105-mm, M2A1, M4						
Charge 1 MV 650 f/s Fuze, PD, M48A1, M48A2 and M51A4 (0.15 sec. delay)	1,000	126	170	24	12	2
	2,000	272	285	15	13	3
Charge 2 MV 710 f/s Fuze, PD, M48A1, M48A2 and M51A4 (0.15 sec. delay)	1,000	104	145	27	12	2
	2,000	226	260	19	15	3
	3,000	376	315	10	10	3
Charge 3 MV 780 f/s Fuze, PD, M48A1, M48A2 and M51A4 (0.15 sec. delay)	1,000	87	125	31	12	2
	2,000	188	230	23	16	3
	3,000	304	295	15	14	3
Charge 4 MV 875 f/s Fuze, PD, M48A1, M48A2 and M51A4 (0.15 sec. delay)	1,000	69	105	36	11	2
	2,000	147	195	29	17	3
	3,000	237	265	21	17	4
	4,000	343	305	14	13	3
Charge 5 MV 1,020 f/s Fuze, PD, M48A1, M48A2 and M51A4 (0.15 sec. delay)	1,000	51	80	44	10	2
	2,000	109	155	37	17	3
	3,000	174	220	30	20	4
	4,000	247	270	23	19	4
	5,000	331	305	17	15	4
	6,000	430	315	10	9	3
Charge 6 MV 1,235 f/s Fuze, PD, M48A1, M48A2 and M51A4 (0.15 sec. delay)	1,000	39	65	51	10	2
	2,000	86	125	43	17	3
	3,000	138	185	36	20	4
	4,000	198	235	30	21	4
	5,000	265	280	24	20	4
	6,000	339	305	17	16	4
	7,000	422	315	10	10	4
Charge 7 MV 1,550 f/s Fuze, PD, M48A1, M48A2 and M51A4 (0.15 sec. delay)	1,000	25	45	65	8	2
	2,000	60	95	54	15	3
	3,000	104	145	44	19	4
	4,000	156	200	37	22	4
	5,000	214	250	29	22	5
	6,000	278	285	23	20	5
	7,000	348	310	17	16	4
	8,000	423	315	10	10	4

Note. Data for charges 1–5 applies also to howitzer, 105-mm, M3.

Table XLIV. Ricochet Data: 155-mm HE Shell M107 and 155-mm Howitzer

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burst
	yd	mils	mils	yd	ft	ft
Howitzer, 155-mm, M1						
Charge 1						
MV 680 f/s	1,000	112	155	26	12	2
Fuze, PD, M51A3	2,000	240	265	18	14	3
and M51A4	3,000	397	315	9	8	3
(0.15 sec. delay)						
Charge 2						
MV 770 f/s	1,000	87	125	31	12	2
Fuze, PD, M51A3	2,000	185	225	24	16	3
and M51A4	3,000	297	295	16	14	3
(0.15 sec. delay)	4,000	436	315	7	7	3
Charge 3						
MV 880 f/s	1,000	68	105	37	12	2
Fuze, PD, M51A3	2,000	141	185	30	17	3
and M51A4	3,000	223	255	23	18	4
(0.15 sec. delay)	4,000	318	300	16	15	4
	5,000	433	315	8	8	3
Charge 4						
MV 1,020 f/s	1,000	50	80	45	10	2
Fuze, PD, M51A3	2,000	106	150	38	17	3
and M51A4	3,000	168	215	31	20	4
(0.15 sec. delay)	4,000	237	265	24	20	4
	5,000	315	300	18	16	4
	6,000	406	315	11	11	4
Charge 5						
MV 1,220 f/s	1,000	38	60	51	9	2
Fuze, PD, M51A3	2,000	82	120	45	16	3
and M51A4	3,000	133	180	38	20	4
(0.15 sec. delay)	4,000	188	230	32	22	5
	5,000	249	270	26	21	5
	6,000	315	300	20	18	4
	7,000	389	315	13	12	4
Charge 6						
MV 1,520 f/s	1,000	24	40	66	7	2
Fuze, PD, M51A3	2,000	54	85	56	14	3
and M51A4	3,000	92	130	48	19	4
(0.15 sec. delay)	4,000	138	185	40	22	4
	5,000	190	230	34	23	5
	6,000	247	270	27	22	5
	7,000	307	300	21	19	5
	8,000	371	310	16	15	4
	9,000	439	315	10	10	4

Table XLIV. Ricochet Data: 155-mm HE Shell M107 and 155-mm Howitz Continued

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE i heigl of bu
	yd	mils	mils	yd	ft	ft
Howitzer, 155-mm, M1						
Charge 7						
MV 1,850 f/s	1,000	15	30	83	7	1
Fuze, PD, M51A3	2,000	35	60	74	13	2
and M51A4	3,000	60	95	64	18	4
(0.15 sec. delay)	4,000	92	130	55	21	4
	5,000	130	175	46	24	5
	6,000	176	220	38	25	5
	7,000	228	260	30	24	5
	8,000	286	290	24	21	5
	9,000	348	310	18	17	4
	10,000	411	315	13	13	4

Table XLV. Ricochet Data: 155-mm HE Shell M101 and 155-mm Gun

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE i heg h of bur
	yd	mils	mils	yd	ft	ft
Gun, 155-mm, M2						
Normal charge						
MV 2,100 f/s	1,000	12	25	96	7	1
Fuze, PD, M51A3	2,000	28	50	86	13	2
and M51A4	3,000	47	75	77	17	3
(0.15 sec. delay)	4,000	70	105	67	21	4
	5,000	98	140	58	24	5
	6,000	132	180	49	26	5
	7,000	173	215	40	26	5
	8,000	221	255	33	25	5
	9,000	276	285	26	22	5
	10,000	336	305	20	18	5
	11,000	399	315	14	14	4
Super charge						
MV 2,800 f/s	1,000	7	20	130	7	1
Fuze, PD, M51A3	2,000	14	30	121	10	2
and M51A4	3,000	22	40	112	13	3
(0.15 sec. delay)	4,000	33	55	102	17	3
	5,000	46	75	93	21	4
	6,000	62	95	84	24	4
	7,000	82	120	74	26	5
	8,000	107	150	65	29	6
	9,000	135	180	56	30	6
	10,000	169	215	47	30	6
	11,000	207	245	39	29	6
	12,000	252	275	31	26	6
	13,000	302	295	24	22	5
	14,000	358	310	19	18	5
	15,000	419	315	14	14	5

Table XLVI. Ricochet Data: 8-in. HE Shell M106 and 8-in. Howitzer

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burst
	yd	mils	mils	yd	ft	ft
Howitzer, 8-in. M2						
Charge 1						
MV 820 f/s	1,000	76	110	34	11	2
Fuze, PD, M51A3	2,000	158	205	27	17	4
and M51A4	3,000	251	275	20	17	4
(0.15 sec. delay)	4,000	358	310	13	12	3
Charge 2						
MV 900 f/s	1,000	63	95	39	11	2
Fuze, PD, M51A3	2,000	132	180	32	17	3
and M51A4	3,000	206	245	26	19	4
(0.15 sec. delay)	4,000	291	290	19	17	4
	5,000	387	315	12	11	3
Charge 3						
MV 1,000 f/s	1,000	50	80	44	10	2
Fuze, PD, M51A3	2,000	106	150	38	17	3
and M51A4	3,000	167	215	31	20	4
(0.15 sec. delay)	4,000	235	265	25	20	4
	5,000	309	300	19	17	4
	6,000	393	315	13	12	4
Charge 4						
MV 1,150 f/s	1,000	41	65	50	10	2
Fuze, PD, M51A3	2,000	86	125	44	16	3
and M51A4	3,000	137	185	38	21	4
(0.15 sec. delay)	4,000	192	235	32	22	5
	5,000	252	275	26	21	5
	6,000	317	300	19	18	4
	7,000	388	315	14	13	4
Charge 5						
MV 1,380 f/s	1,000	28	50	60	9	2
Fuze, PD, M51A3	2,000	64	100	52	15	3
and M51A4	3,000	107	150	45	20	4
(0.15 sec. delay)	4,000	154	200	38	23	5
	5,000	206	245	32	23	5
	6,000	262	280	26	22	5
	7,000	321	300	20	19	5
	8,000	384	315	15	14	4

Table XLVI. Ricochet Data: 8-in. HE Shell M106 and 8-in. Howitzer—Contin

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burs
	yd	mils	mils	yd	ft	ft
Howitzer, 8-in. M2						
Charge 6						
MV 1,640 f/s	1,000	20	35	73	8	2
Fuze, PD, M51A3	2,000	45	70	65	14	3
and M51A4	3,000	75	110	56	19	4
(0.15 sec. delay)	4,000	111	155	48	22	4
	5,000	154	200	41	24	5
	6,000	203	240	34	24	5
	7,000	256	275	28	23	5
	8,000	313	300	22	20	5
	9,000	372	310	17	16	5
	10,000	434	315	11	11	4
Charge 7						
MV 1,950 f/s	1,000	16	30	92	8	2
Fuze, PD, M51A3	2,000	33	55	80	13	3
and M51A4	3,000	53	85	71	18	4
(0.15 sec. delay)	4,000	76	110	63	21	4
	5,000	105	150	55	24	5
	6,000	139	185	47	26	5
	7,000	180	225	40	27	6
	8,000	227	260	33	26	6
	9,000	279	285	26	23	5
	10,000	335	305	21	19	5
	11,000	393	315	15	14	4

Table XLVII. Ricochet Data: 8-in. HE Shell M103 and 8-in. Gun

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burst
	yd	mils	mils	yd	ft	ft
Gun, 8-in., M1						
Reduced charge						
MV 2,100 f/s	1,000	11	20	97	6	1
Fuze, PD, M51A4	2,000	24	40	89	10	2
Mod 3	3,000	39	65	81	15	3
(0.15 sec. delay)	4,000	56	85	74	18	3
	5,000	75	110	66	22	4
	6,000	97	140	59	24	5
	7,000	122	170	52	26	5
	8,000	150	195	46	26	5
	9,000	183	225	40	27	6
	10,000	220	255	35	27	6
	11,000	261	280	30	26	6
	12,000	306	295	27	24	6
	13,000	357	310	24	23	6
	14,000	412	315	23	22	7

Table XLVII. Ricochet Data: 8-in. HE Shell M103 and 8-in. Gun—Continued

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burst
	yd	mils	mils	yd	ft	ft
Gun, 8-in., M1						
Normal charge MV 2,600 f/s Fuze, PD, M51A4 Mod 3 (0.15 sec. delay)	15,000	272	285	32	27	6
	16,000	310	300	29	26	6
	17,000	351	310	27	25	7
	18,000	395	315	25	24	7
	19,000	442	315	24	23	9
Super charge MV 2,850 f/s Fuze, PD, M51A4 Mod 3 (0.15 sec. delay)	17,000	275	285	33	29	6
	18,000	309	300	30	27	6
	19,000	347	305	28	26	7
	20,000	387	315	26	25	8
	21,000	430	315	26	24	9
Reduced charge MV 2,100 f/s Fuze, PD, M51A1 Mod 1 and M51A2 Mod 3 (0.05 sec. delay)	1,000	11	20	33	2	0
	2,000	24	40	31	4	1
	3,000	39	65	28	5	1
	4,000	56	85	26	7	1
	5,000	75	110	24	8	2
	6,000	97	140	22	9	2
	7,000	122	170	19	10	2
	8,000	150	195	17	10	2
	9,000	183	225	15	10	2
	10,000	220	255	13	10	2
	11,000	261	280	11	9	2
	12,000	306	295	9	8	2
	13,000	357	310	7	6	2
	14,000	412	315	5	5	2
Normal charge MV 2,600 f/s Fuze, PD, M51A1 Mod 1 and M51A2 Mod 3 (0.05 sec. delay)	15,000	272	285	11	10	2
	16,000	310	300	9	8	2
	17,000	351	310	7	7	2
	18,000	395	315	6	6	2
	19,000	442	315	4	4	2
Super charge MV 2,850 f/s Fuze, PD, M51A1 Mod 1 and M51A2 Mod 3 (0.05 sec. delay)	17,000	275	285	12	10	2
	18,000	309	300	10	9	2
	19,000	347	305	8	7	2
	20,000	387	315	6	6	2
	21,000	430	315	5	4	2

Table XLVIII. Ricochet Data: 240-mm HE Shell M114 and 240-mm Howitzer

	Range	Angle of fall	Angle of recovery	Impact to burst	Height of burst	PE in height of burst
	yd	mils	mils	yd	ft	ft
Howitzer, 240-mm, M1						
Charge 1 MV 1,500 f/s Fuze, PD, M51A3 and M51A4 (0.15 sec. delay)	9,000	371	310	17	16	5
	10,000	428	315	11	11	4
Charge 2 MV 1,740 f/s Fuze, PD, M51A3 and M51A4 (0.15 sec. delay)	11,000	405	315	15	14	4
Charge 3 MV 2,020 f/s Fuze, PD, M51A3 and M51A4 (0.15 sec. delay)	13,000	407	315	15	14	4

Note. Few ricochets expected with charge 4 at minimum elevation with level carriage.

Section III. ARTILLERY FIRE AGAINST ARTILLERY MATÉRIEL

66. General

For several gun-ammunition combinations, ranges, and types of fire tables XLIX and L give the number of rounds to be fired to obtain a certain degree of destruction of enemy artillery. With regard to total weight of projectiles, there is an advantage in using the smallest shell which will reach the target. Frequently, in time fire with shell of the same caliber, there is an advantage in using that shell with the highest muzzle velocity.

67. The Target

a. DIMENSIONS. The target required in the following tables is an AA gun with the dimensions indicated on figure 97.

b. DAMAGE. In general the degree of destruction considered is that necessary to prevent temporarily the use of the piece as an antiaircraft weapon. The most vulnerable part of a piece is the counter recoil mechanism. Perforation of the counter recoil gas cylinder is considered as a primary disabling condition but not the only condition which will

prevent the use of the piece temporarily. Somewhat more damage is required to prevent the use of the piece against ground targets, for example, against tanks, and for this the figures of the tables should be increased about 20 percent.

c. Other Targets. The number of rounds is approximately correct for *other artillery targets.* They should be increased by not more than 50 percent for more highly resistant targets or for the requirements of more serious damage. If the target piece is of different size than the illustrated weapon, the number of rounds should be altered in inverse proportion. That is, for targets of smaller area, the number of rounds should be increased by about the same factor as the area is smaller, except for fire at very short ranges. Paragraph 61 gives the percent of guns damaged when the number of rounds differs by a given fraction from that listed.

d. Effect of Fire against Personnel. The most common effect of counter battery fire is to prevent manning the guns. For the effect against personnel see section I, chapter 3. In general, the best condition for fire against personnel is also nearly the best for fire against artillery, so that tables XLIX and L indicate the added effect against matériel if anti-personnel fire is conducted.

68. Area Fire

a. Probability. If only the general location of the enemy pieces is known, the fire must be directed over a general area. The number of rounds required for a given probability of damaging one piece known to be in the area is then proportional to the area over which the fire is distributed. The probability of hitting another piece in the area is the same, so the number of rounds required to put out of action half the enemy pieces in the area is independent of the number of enemy guns in the area.

b. Unit Area. The number of rounds per 10,000 square yards of the area over which the fire is directed, required to damage half the enemy pieces located in the area, is listed in table XLIX. The fact that the number of rounds is listed for an area of 10,000 square yards (100 yards square by 100 yards square) is not to be interpreted as meaning that area fire over such a small area is possible without wasting ammunition outside the area. The numbers listed must be multiplied by the total target area in square yards divided by 10,000.

c. Fringe. There is an area at the edge of the target in which the probability of hitting a target with fragments is lower than 50 percent, being in fact 25 percent at edges away from corners. This could be overcome by increasing the number of rounds near the edge. Frequently, however, in area fire the concentration of targets is suspected to be

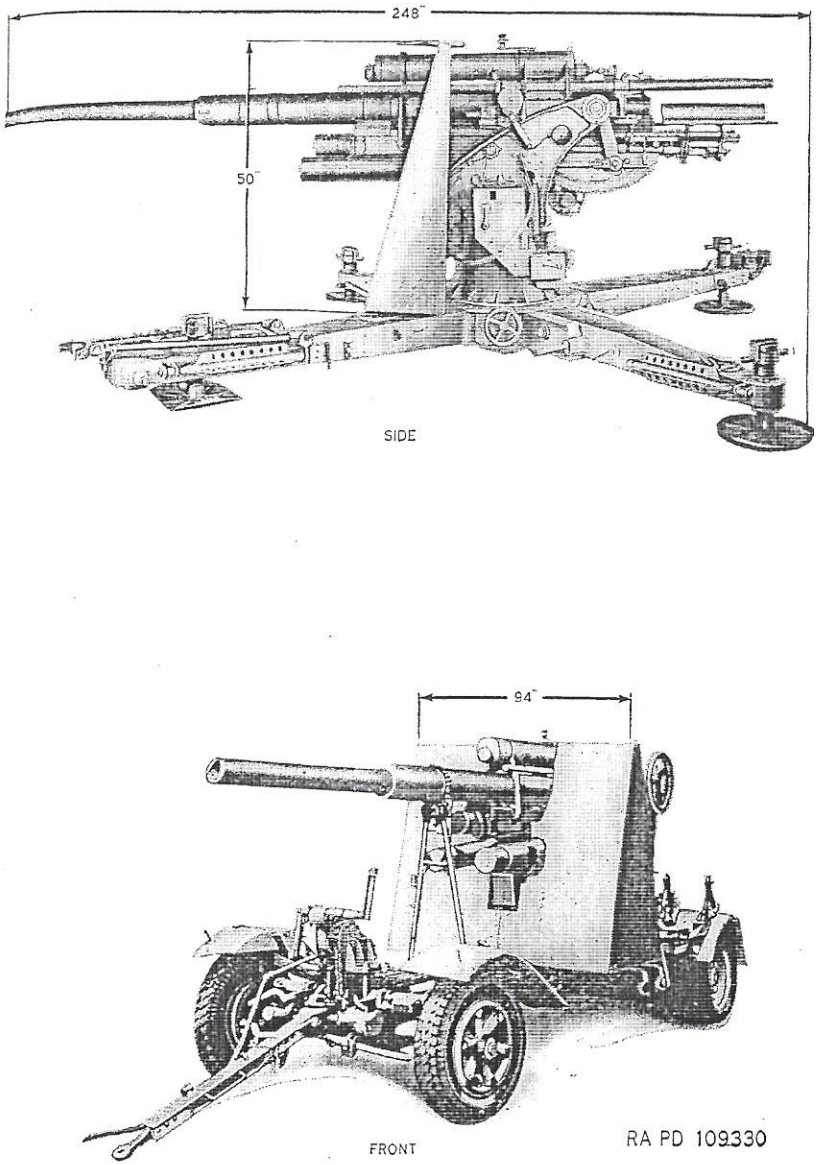


Figure 97. Dimensions of target.

greater at the center of the area and consequently the effect of a round of ammunition is greater here. The significance of the numbers listed under *impact, time,* and *time and impact* is explained in paragraphs 70 and 71.

69. Aimed Fire

If the enemy piece is accurately located, the fire should be directed at the piece itself. Table L lists the number of rounds required for 90-percent probability of damaging the target in aimed fire. The figures for time fire are based on the assumption that the fuze time is set so that the center of burst is at the target. The significance of the numbers listed under *impact, time* and *time and impact* is explained below. Firing table probable errors have been assumed, and consequently the numbers refer to observed fire, well adjusted.

70. Impact Fire

The numbers tabulated opposite *impact* in the tables are those caused by direct hits only. *No damage due to blast or fragments from near misses has been considered,* since this depends on the degree of shielding and the way the weapon is emplaced. These figures consequently are *conservative,* since if no shielding or revetments are present there will be considerable damage due to fragments.

71. Time Fire

The numbers of rounds required for air burst fire are entered opposite *time,* and *time and impact* in the tables.

a. Time. The values tabulated opposite *time* give the number of rounds required when the damage is caused *only* by fragments arising from air bursts. This is listed separately for purpose of general interest.

b. Height of Burst. In table L, aimed fire, the fuze setting is assumed to be such that the center of burst occurs at the target. In table XLIX, area fire, the height of center of burst is assumed to be one mil for ranges up to 10,000 yards, and 30 feet for greater ranges. This is a simple workable rule giving very close to maximum effect of fire against the matériel for the problem in hand. When the probable error is large, a mean height of burst equal to two probable errors in the height of burst as given in the firing table is preferable for maximum effect against personnel. The tabulated numbers are applicable in this case. Due to the dispersion in fuze functioning, half the shell will burst below the center of burst and half above it. In the case of aimed fire, with center of burst at the target and not above it, the half with delayed functioning will strike the ground before bursting. In the case of area fire, with higher center of burst, there still will be a considerable number of shell striking the ground before bursting. These shell may strike the target and destroy it by direct hits. The effect of these hits has been ignored in the line marked *time.* It has been included in the line marked *time and impact.*

c. Time and Impact. The entries under time and impact, therefore, give the combined effect of air burst and direct hits. However, as in the case of the entry on the line marked *impact,* the effect of fragment damage from near miss ground bursts, which occur with the shell fuzed combination time and superquick, is neglected, since this damage depends greatly on the shielding and type of revetment. In the case of minimum shielding the entries are therefore conservative when the combination time and superquick fuze is used.

72. Comparison of Ground Burst and Air Burst

a. No general statement of the relative effectiveness of ground burst and air burst fire is possible since this depends entirely on the emplacements. With no shielding at all by revetments, ground bursts generally are more effective against matériel and personnel, but personnel in foxholes or trenches should be attacked by air burst fire. Since counter battery fire is directed largely against personnel, the numbers listed opposite *time and impact* should indicate the damage done to matériel when air bursts are employed.

b. In the case of aimed fire, except at the longer ranges with the heavier weapons, the *impact* entries are lower than those of *time and impact,* which means that direct hits are more effective than air bursts, and PD fuzes, set superquick, are superior to time fuzes *if the effect against matériel alone is desired.*

c. The added effect of fragment damage from near miss ground bursts, which is neglected in all the numbers listed and depends on the revetments present, will be greatest for the PD fuze set superquick, next for the combination time and superquick setting, and absent for time fuzes with no superquick impact element. While the fragmentation damage from near miss ground bursts is neglected in all cases listed, it does increase the effectiveness of fire against matériel when shielding —such as revetments—is poor or absent. Under conditions of poor shielding the number of rounds given in the tables is affected as follows:

Impact fire (SQ fuze)—number of rounds materially reduced.

Air burst or impact (TSQ fuze)—number of rounds somewhat reduced.

Air burst only (time fuze without superquick impact element)—number of rounds unchanged.

73. Comparison of Aimed Area Fire

The numbers listed in the tables for the same gun ammunition combination and range are not directly comparable, since they refer to entirely different quantities, those in aimed fire being number of rounds per enemy piece attacked and those in area fire number of rounds per 10,000 square yards area fired upon. In general, *aimed fire,* if the enemy pieces are accurately located, *is at least as good as area fire and is almost always better* when the same height of center of burst is used. At great ranges, where dispersion is large, and with very many enemy pieces in a small area, area fire may be essentially as good, since the rounds fired at neighboring enemy pieces may overlap due to dispersion. In this case, rounds aimed at one piece may damage its neighbor. If this situation of extremely high area concentration of enemy pieces holds, then the numbers given for aimed fire may be high (since any given weapon may be damaged by rounds aimed at its neighbor) and the numbers pertaining to area fire may represent the true damage figures, even if aimed fire is used. In general, it is most profitable to fire the same number of rounds at each enemy piece, all other factors being equal.

Table XLIX. Area Fire Against Artillery

(Number of rounds required per unit area (10,000 sq yd) for 50 percent effect)

Gun and ammunition	Muzzle velocity f/s	Range yd	Number of shell required per unit area for 50% effect		
			Impact	Time	Time and impact
Howitzer, 75-mm, M1A1, M2, M3. Shell, HE, M48, w/fuze, TSQ, M54 or fuze, PD, M48A2. Charge 4.	1250	2000	210	230	170
	....	5000	680	700	500
Howitzer, 155-mm, M1 ..... Shell, HE, M107, w/fuze, MT, M671A or fuze, PD, M51A3. Charge 7.	....	2000	70	43	38
	1850	5000	260	67	59
		10000	790	160	150
		15000	1400	300	280
Gun, 155-mm, M1, M1A1, M2 ... Shell, HE, M101, w/fuze, MT, M67A1 or fuze, PD, M51A3. Supercharge.	....	2000	27	26	26
	2800	5000	92	53	48
		10000	330	92	83
		15000	810	180	160
		20000	1300	320	290
		25000	1700	....	....
Howitzer, 240-mm, M1 ..... Shell, HE, M114, w/fuze, MT, M67A1 or fuze, PD, M51A3. Charge 4.	....	....	....	....	....
	2300	20000	1100	120	110
		25000	1400	160	150

Table L. Aimed Fire Against Artillery

(Number of rounds required for 90 percent probability of at least one effective hit

Gun, shell, and fuze	Muzzle velocity f/s / Charge	Range yd	Number of rounds required for 90% probability of one or more effective hits		
			Impact	Time	Time an impact
Howitzer, 75-mm, M1A1, M2, M3 Shell, HE, M48, w/fuze, TSQ, M54 or fuze, PD, M48 and mod	1250	2,000	24	340	43
	Charge 4	5,000	460	1,400	560
Gun, 75-mm, M3, M6, M17 Shell, HE, M48, w/fuze, TSQ, M54 or fuze, PD, M48 and mods	1980	2,000	7	340	15
	Supercharge	5,000	120	790	180
Gun, 76-mm, M1A1C, M1A2 Shell, HE, M42A1, w/fuze, MT, M43A5, or fuze, PD, M48 and mods	2700	2,000	6	270	13
	Normal charge	5,000	55	430	87
Gun, 90-mm, M1, M1A1, M2, M3 Shell, HE, M71, w/fuze, MT, M43A5 or fuze, PD, M48, mods	2700	2,000	3	260	7
	Normal charge	5,000	42	360	68
		10,000	770	1,400	730
Howitzer, 105-mm, M2A1, M4 Shell, HE, M1 w/fuze, TSQ, M54 or fuze, PD, M48, mods	1020	2,000	24	250	41
	Charge 5*	5,000	460	820	430
	1550	2,000	6	270	13
	Charge 7	5,000	91	450	130
Howitzer, 155-mm, M1 Shell, HE, M107, w/fuze, MT, M67A1 or fuze, PD, M51, mods	1220	2,000	7	240	14
	Charge 5	5,000	69	320	96
	1850	2,000	3	340	7
	Charge 7	5,000	23	320	41
		10,000	250	590	270
		15,000	2,300	1,900	1,400

* Also applies to M3 howitzer for this charge.

Table L. Aimed Fire Against Artillery—Continued

(Number of rounds required for 90 percent probability of at least one effective hit)

Gun, shell, and fuze	Muzzle velocity f/s / Charge	Range yd	Number of rounds required for 90% probability of one or more effective hits		
			Impact	Time	Time and impact
Gun, 155-mm, M2 Shell, HE, M101, w/fuze, MT, M67A1 or fuze, PD, M51, mods	2100 / Normal charge	5,000	81	330	110
		10,000	570	700	430
		15,000	2,300	1,800	1,300
	2800 / Supercharge	2,000	9	520	18
		5,000	48	460	80
		10,000	330	590	310
		15,000	2,300	960	790
		20,000	4,500	2,500	1,800
		25,000	11,000	4,500	4,000
Howitzer, 8-inch, M2 Shell, HE, M106, w/fuze, MT, M67A1 or fuze, PD, M51, nods	1380 / Charge 5	2,000	3	210	7
		5,000	28	220	45
		10,000	380	390	250
	1950 / Charge 7	5,000	3	290	7
		10,000	54	280	78
		15,000	330	430	260
Gun, 8-inch, M1 Shell, HE, M103, w/fuze, MT, M67A1 or fuze, PD, M51A2, Mod 3	2600 / Normal charge	15,000	130	410	160
		20,000	770	1,100	640
		25,000	2,300	3,100	1,900
	2850 / Supercharge	20,000	1,100	1,400	850
		25,000	2,300	3,400	1,900
		30,000	25,000	7,000	6,200

Table L. Aimed Fire Against Artillery—Continued

(Number of rounds required for 90 per cent probability of at least one effective hit)

Gun, shell, and fuze	Muzzle velocity f/s / Charge	Range yd	Number of rounds required for 90% probability of one or more effective hits		
			Impact	Time	Time and impact
Howitzer, 240-mm, M1 Shell, HE, M114, w/fuze, MT, M67A1 or fuze, PD, M51, mods	1500 / Charge 1	10,000	330	320	220
		15,000	2,300	1,200	950
	1740 / Charge 2	15,000	1,100	1,600	930
	2300 / Charge 4	20,000	2,300	1,000	820
		25,000	7,700	2,400	2,100

Section IV. ARMOR PENETRATION

74. General

This section provides information pertaining to the performance of armor-piercing projectiles against homogeneous and face-hardened armor plate. The various theories and analyses of the mechanics of armor penetration will not be dealt with in this discussion, although such knowledge is necessary for better evaluation of results obtained from test fire rings of projectiles against armor plate. It also allows these findings to be interpreted more easily and accurately. It is from the test firings that data are obtained and compiled as a basis for determining penetrations.

75. Armor Penetration and Striking Velocity Curves

a. GRAPHS. Armor penetration data are presented graphically for AP bullets and artillery projectiles fired against armor plate at various angles of impact and plate obliquities (figs. 98 to 119). These data are shown for rolled and/or wrought homogeneous armor and face-hardened plates. The data presented were obtained against quality of armor plate prevailing during World War II. As a result the data are for rolled homogeneous armor plate on thicknesses of plate less than 5 inches; above 5 inches the data presented are based on results obtained against forged, finished rolled homogeneous plates, and forged homogeneous plates. The data do not pertain to cast homogeneous armor plate. From the charts, the thickness of armor plate which can be penetrated at a given range or striking velocity can be determined. It will be noted that portions of

the penetration curves are shown as broken lines. This represents estimated performance for which actual firing data have not been obtained. Characteristics of ammunition, upon which the charts are based, are given in table LI.

b. PENETRATION. The penetration curves in this section are based upon firing conducted at proving grounds. The curves are plots of values of ballistic limits obtained by averaging the striking velocities required to obtain a complete penetration and a partial penetration. The velocities for partial penetration are always lower than for the complete but are within 50 feet per second of those for complete penetration.

(1) Complete penetrations are obtained when—

(*a*) An intact projectile or the greater portion of a shattered projectile perforates the armor plate.

(*b*) Nonperforating projectiles reject fragments from the back of the armor plate, or fragments of the projectile pass through the armor plate, with sufficient force for the fragments to perforate a target, such as a 1-inch thick plywood panel, placed a short distance behind the armor plate.

(2) A partial penetration is any result that does not meet (*a*) or (*b*) above.

76. Examples

a. CHARTS. The following examples and the chart shown in figure 98 illustrate the use of the striking velocity and armor penetration curves. The range scale in yards and the penetration scale in inches are shown along the bottom of the chart; the striking velocity in feet per second is shown along the left hand border; the striking velocity curve is designated by showing the muzzle velocity upon which it is based; the penetration curves are designated to indicate the obliquity upon which they are based.

b. EXAMPLE 1. (1) *Given.* 3-inch plate thickness.

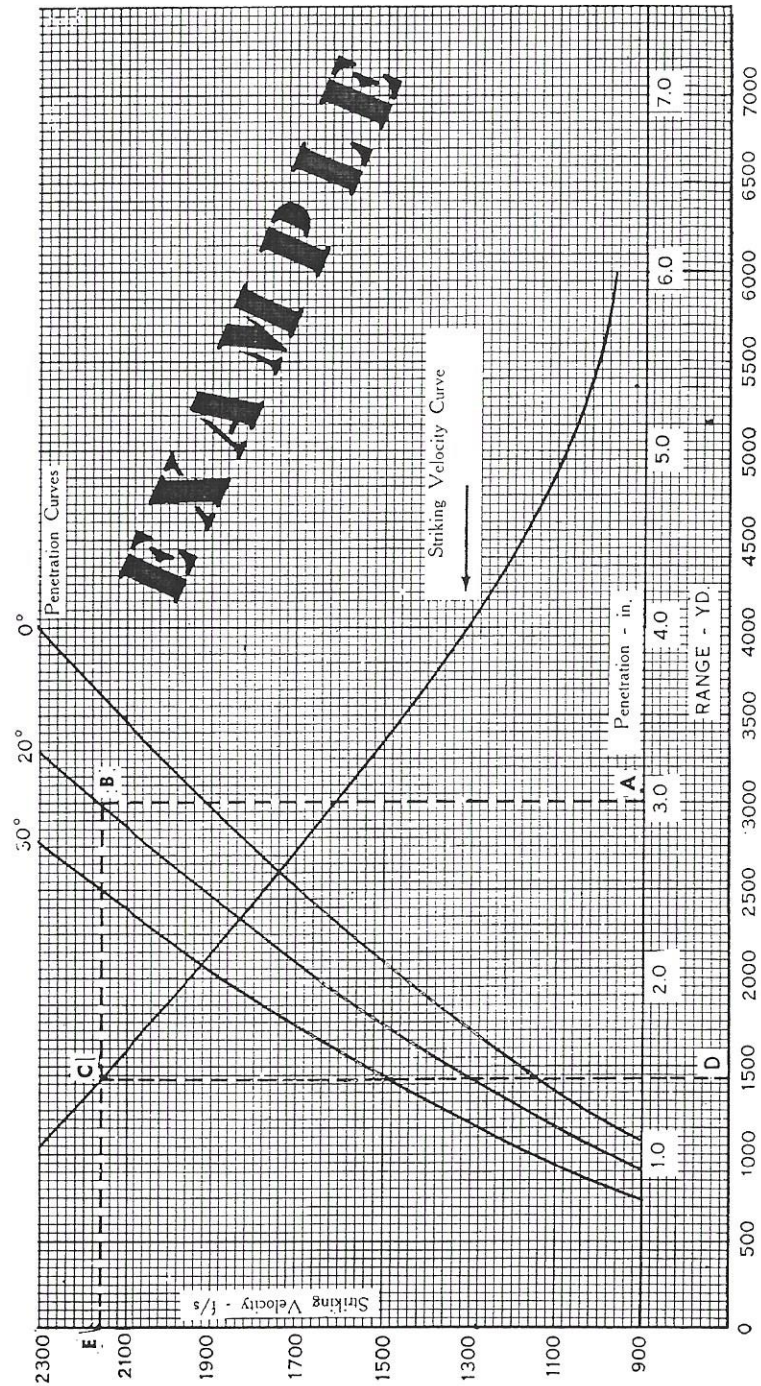
(2) *Required.* The striking velocity and maximum range at which penetration at 20-degree obliquity can be achieved.

(3) *Solution.* (*a*) Enter the penetration scale at point A which represents 3-inch plate thickness.

(*b*) Proceed upward along the vertical line until the intersection with the 20-degree obliquity penetration curve is reached at B.

(*c*) From B proceed left along a line until the intersection with the striking velocity curve at C is reached.

(*d*) From C continue, first, left along the horizontal line to E where the striking velocity of 2,160 feet per second can be read, then downward from C along the vertical line to D where the range of 1,430 yards is found. Thus, a striking velocity of 2,160 feet per second is needed to



RA PD 109331

Table LI. Armor-Piercing Ammunition Characteristics

(These characteristics were used in the computation of the armor penetration and striking velocity curves, figures 99 to 119.)

Projectile model and caliber	Proj. Wt lb	Gun	Muzzle vel f/s	Based on**
.30-cal. AP, M2	166 grains	24-in. barrel MG	2,775	$C_5 = 0.250$*
.50-cal. AP, M2	708 grains	36-in. barrel MG 45-in. barrel MG	2,835 2,935	$C_5 = 0.458$ $C_5 = 0.458$
20-mm, AP-T, M95	2,000 grains	AN-M2	2,800	$C_5 = 0.403$
37-mm, APC-T, M51	1.92	M6	2,900	$C_6 = 0.544$
37-mm, APC-T, M59	1.91	AN-M9 M1A2	2,800 2,050	$C_1 = 0.492$ $C_1 = 0.610$*
37-mm, AP-T, M80	1.66	AN-M9	3,050 1,825	$C_1 = 0.78$ $C_1 = 0.78$
40-mm, AP-T, M81 or M81A1	1.96	M1	2,870	$C_6 = 0.615$*
57-mm, APC-T, M86 w/fuze, BD, M72	7.27	M1	2,700	$C_6 = 1.31$
75-mm, APC-T, M61 or M61A1 w/fuze, BD, M66A1	14.96	AN-M5A1 M10, M3, M6, M17	2,030	FT75-AY-1
76-mm, APC-T, M62 or M62A1 w/fuze, BD, M66A1	15.44	76-mm, M1A1C, M1A2	2,600	FT76-C-1
76-mm, HVAP-T, M93	9.36	76-mm, M1A1C, M1A2	3,400	FT76-C-1
90-mm, APC-T, M82 w/fuze, BD, M68	24.11	M1, M1A1, M2, M3	2,800 2,670	FT90-F-1
90-mm, HVAP-T, M304	16.80	M1, M1A1, M2, M3	3,350	FT90-F-1

* Variable ballistic coefficient.

** Striking velocity curves are based on calculation made by Siacci's method, using the indicated ballistic coefficients unless a firing table number is indicated.

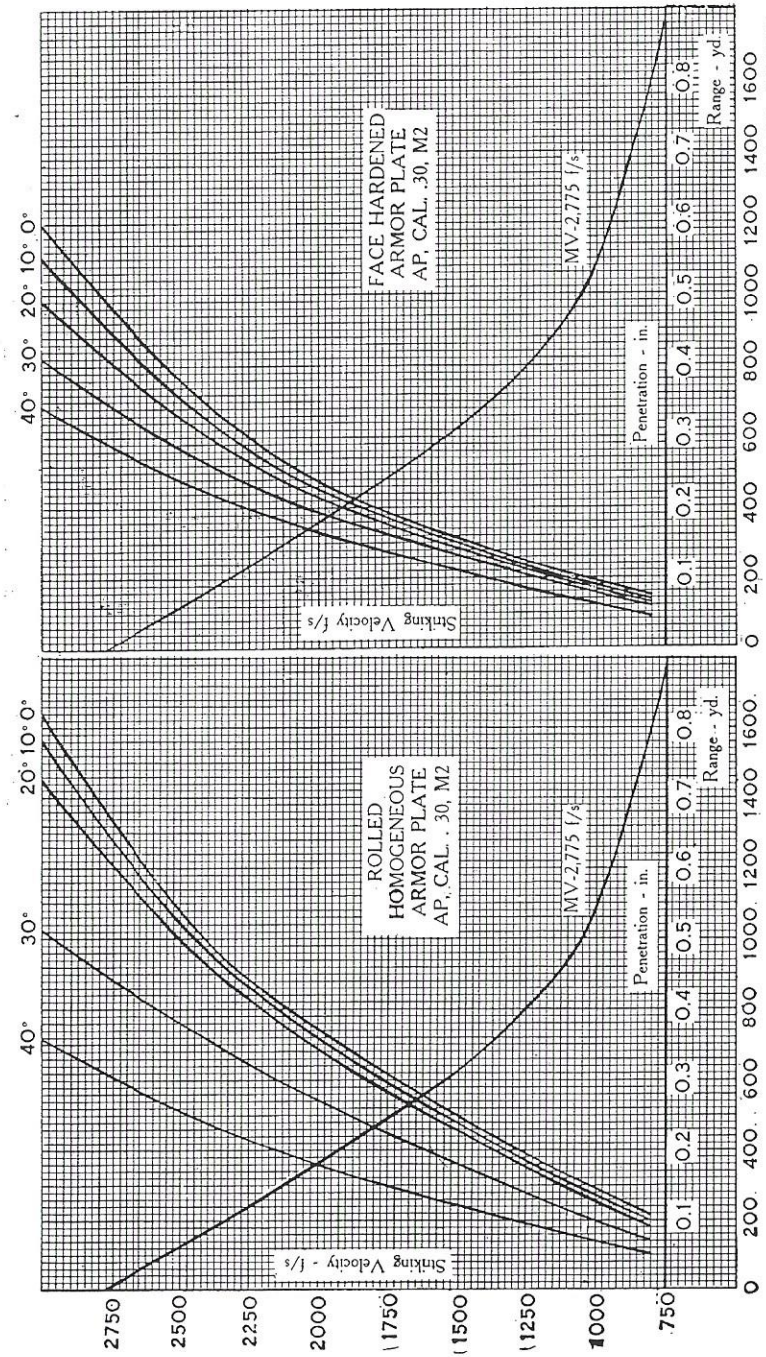


Figure 99. Striking velocity vs armor penetration and range—cal. .30 AP bullet M2.

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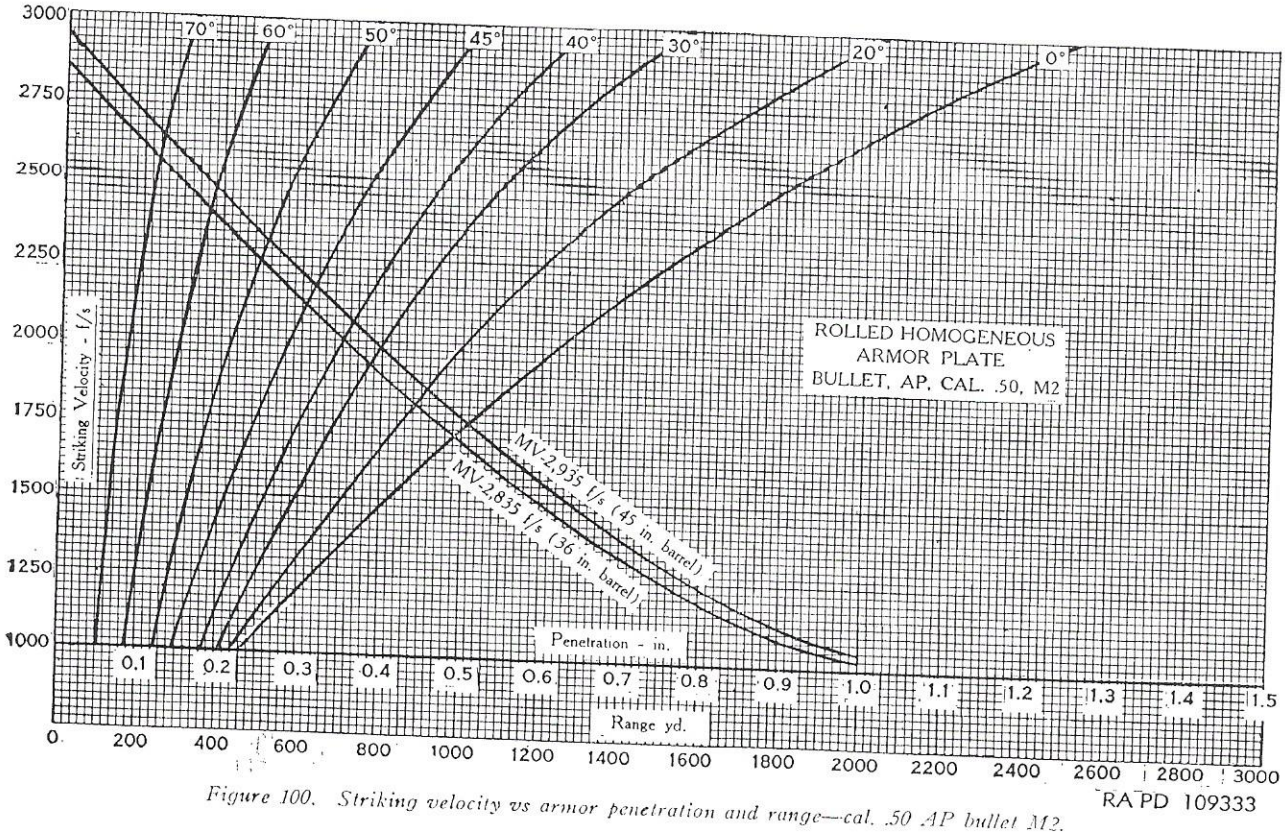


Figure 100. Striking velocity vs armor penetration and range—cal. .50 AP bullet M2.

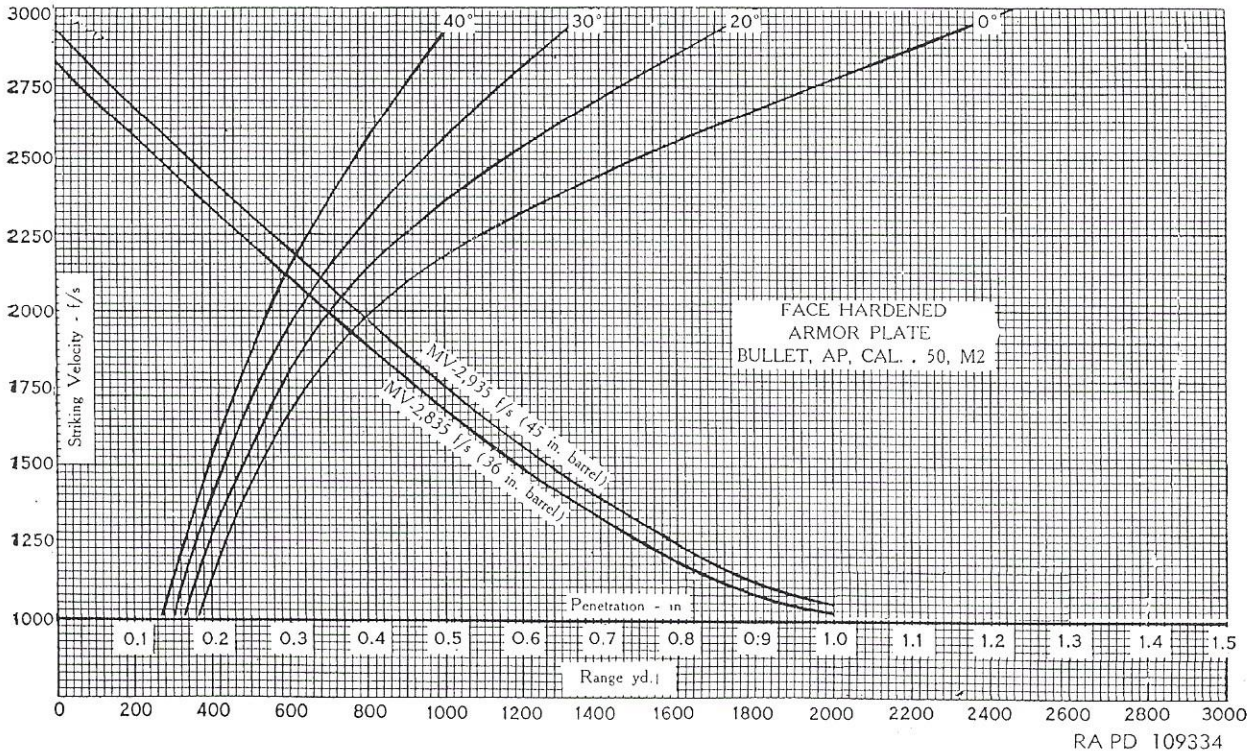


Figure 101. Striking velocity vs armor penetration and range—cal. .50 AP bullet M2.

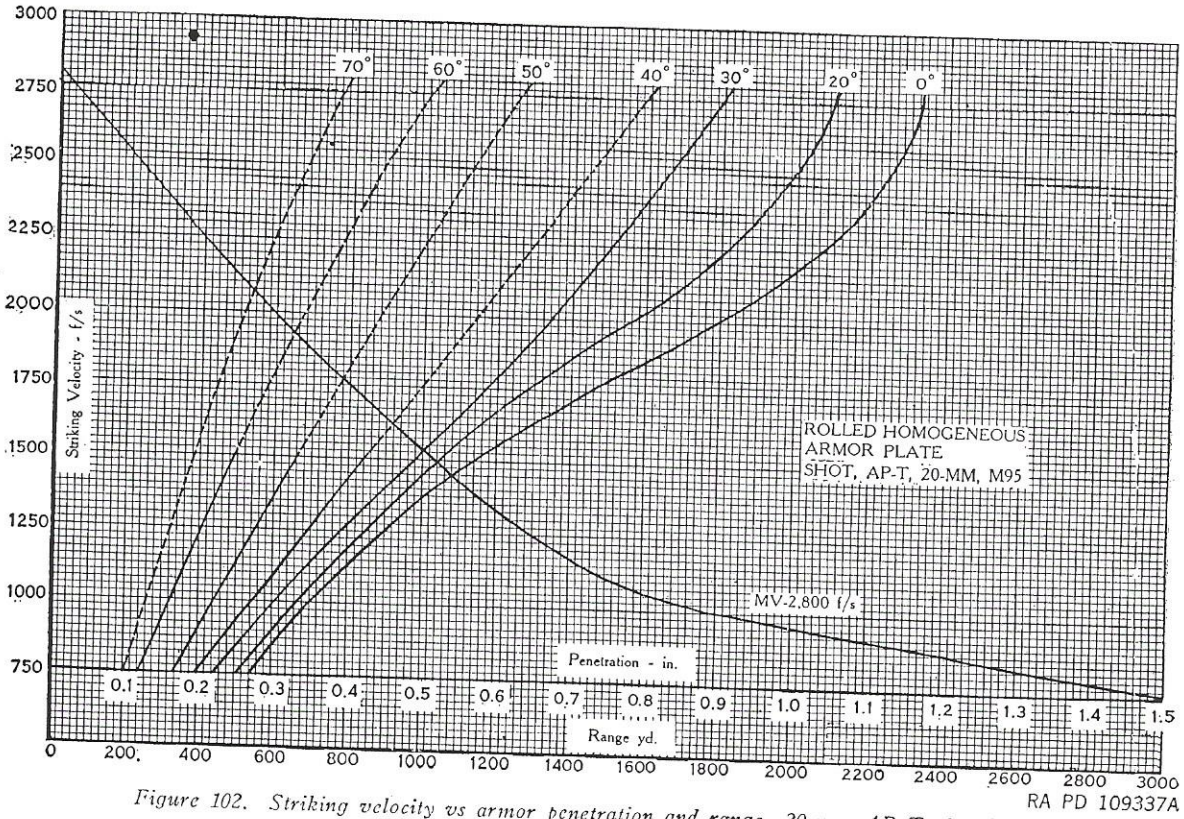


Figure 102. Striking velocity vs armor penetration and range—20-mm AP-T shot M95.

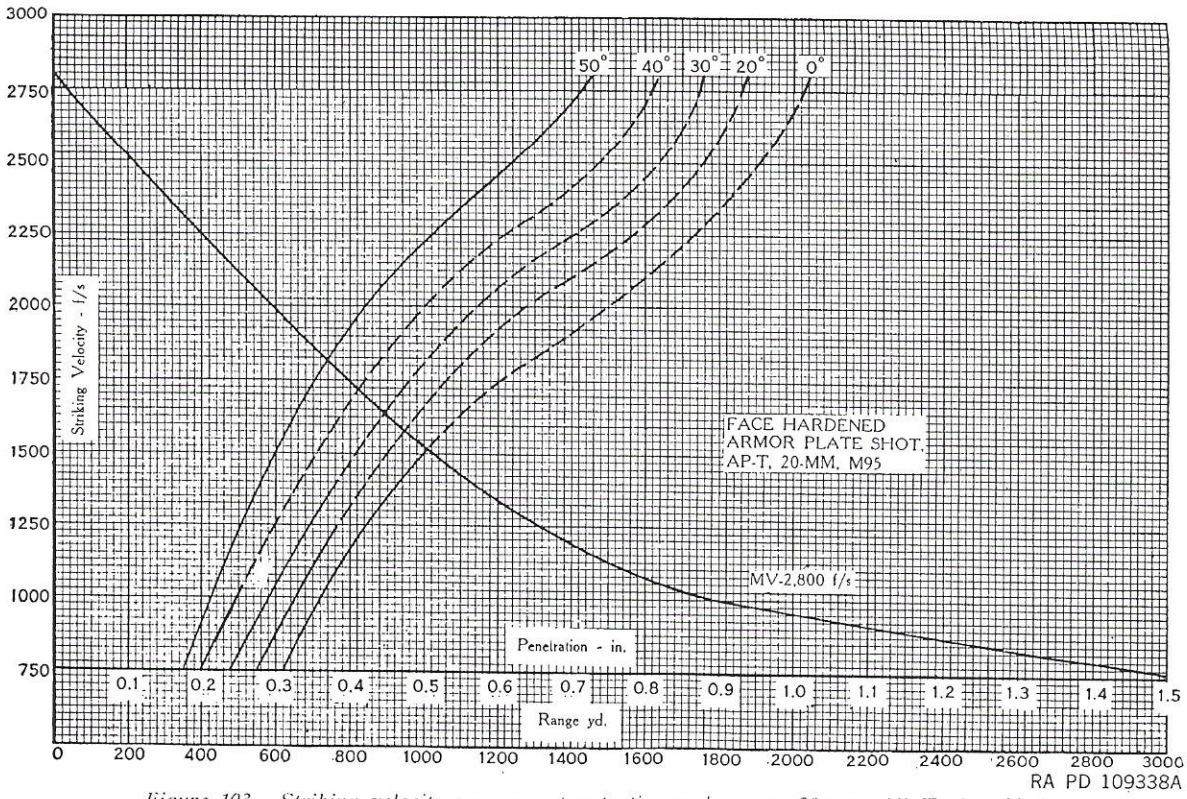


Figure 103. Striking velocity vs armor penetration and range—20-mm AP-T shot M95.

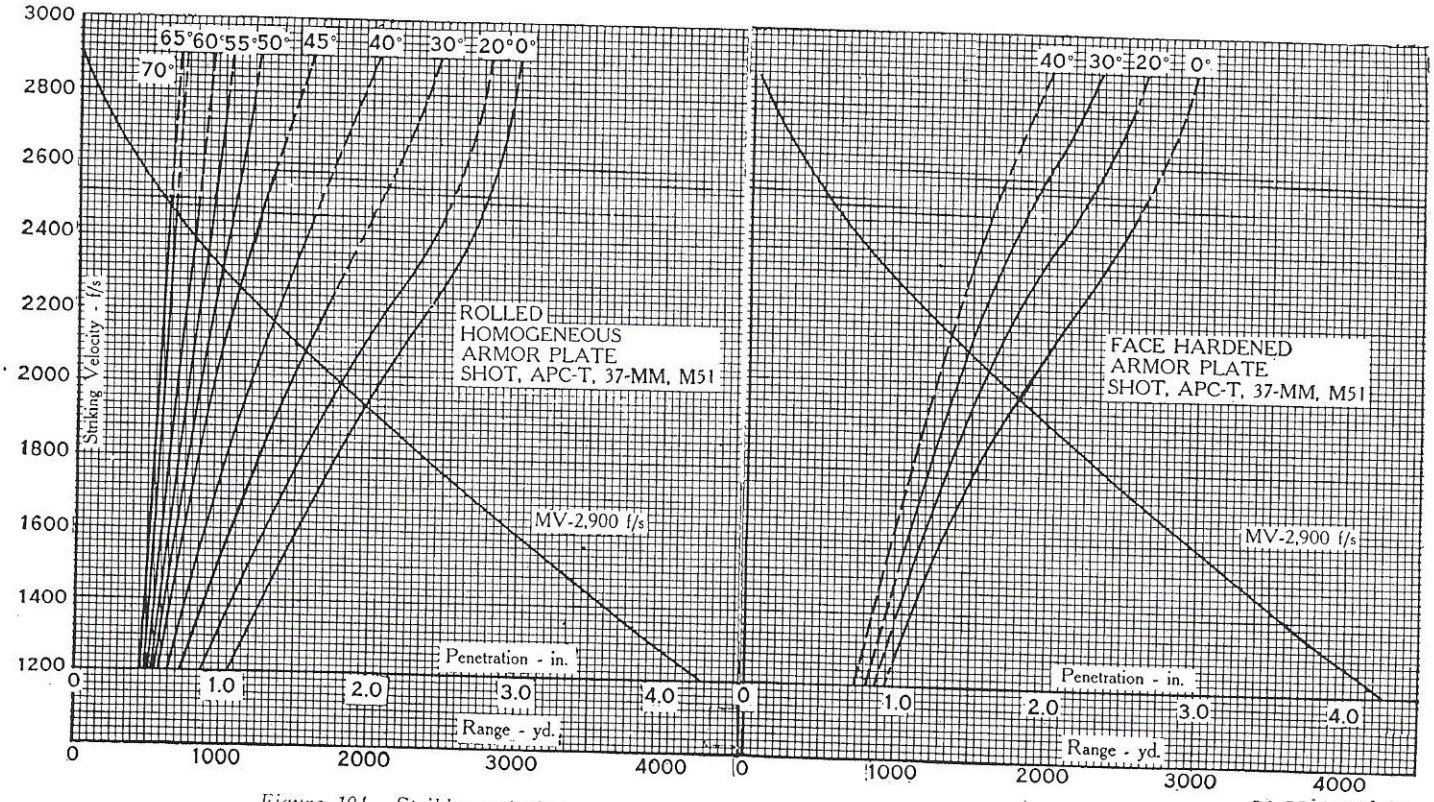


Figure 104. Striking velocity vs armor penetration and range—37-mm APC–T shot M51.

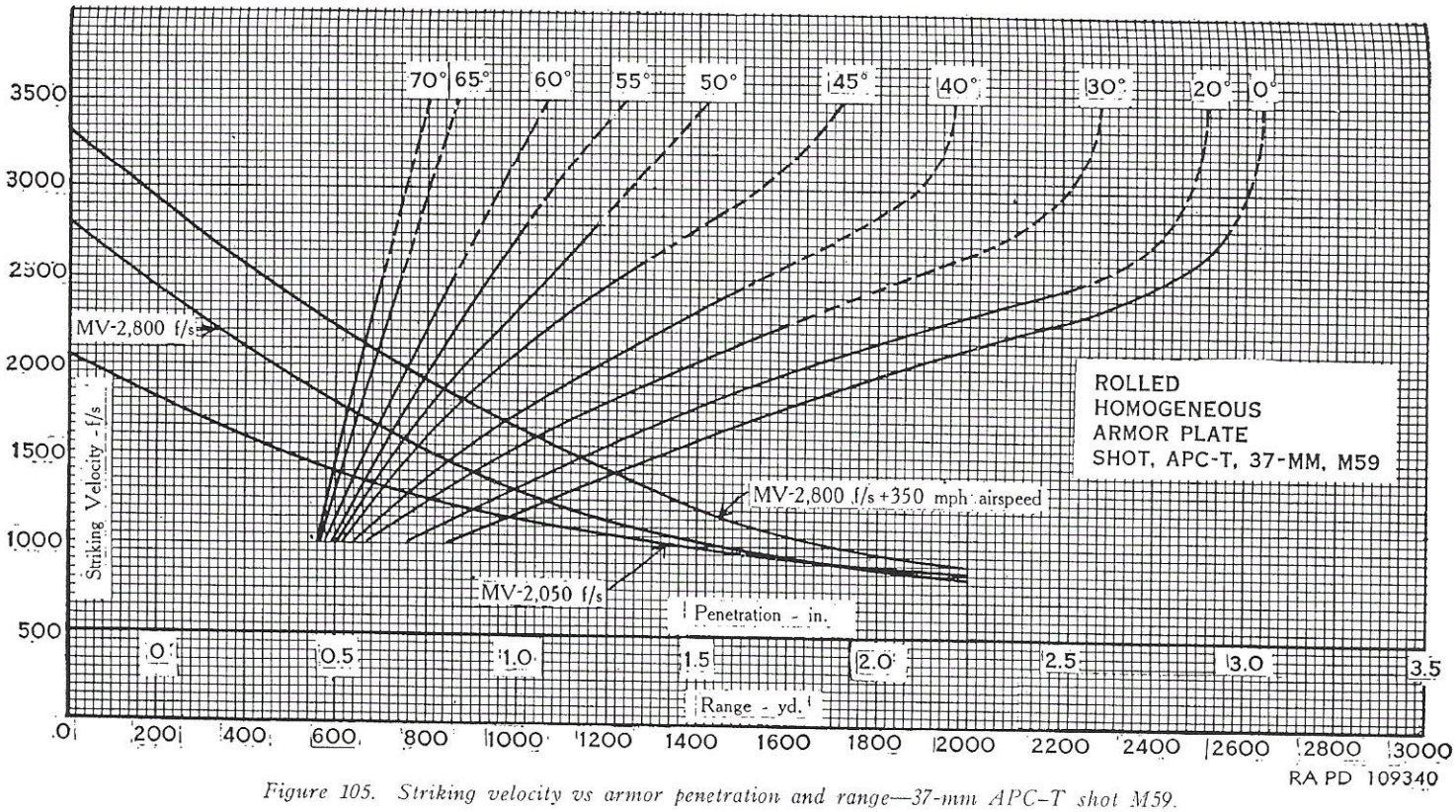


Figure 105. Striking velocity vs armor penetration and range—37-mm APC–T shot M59.

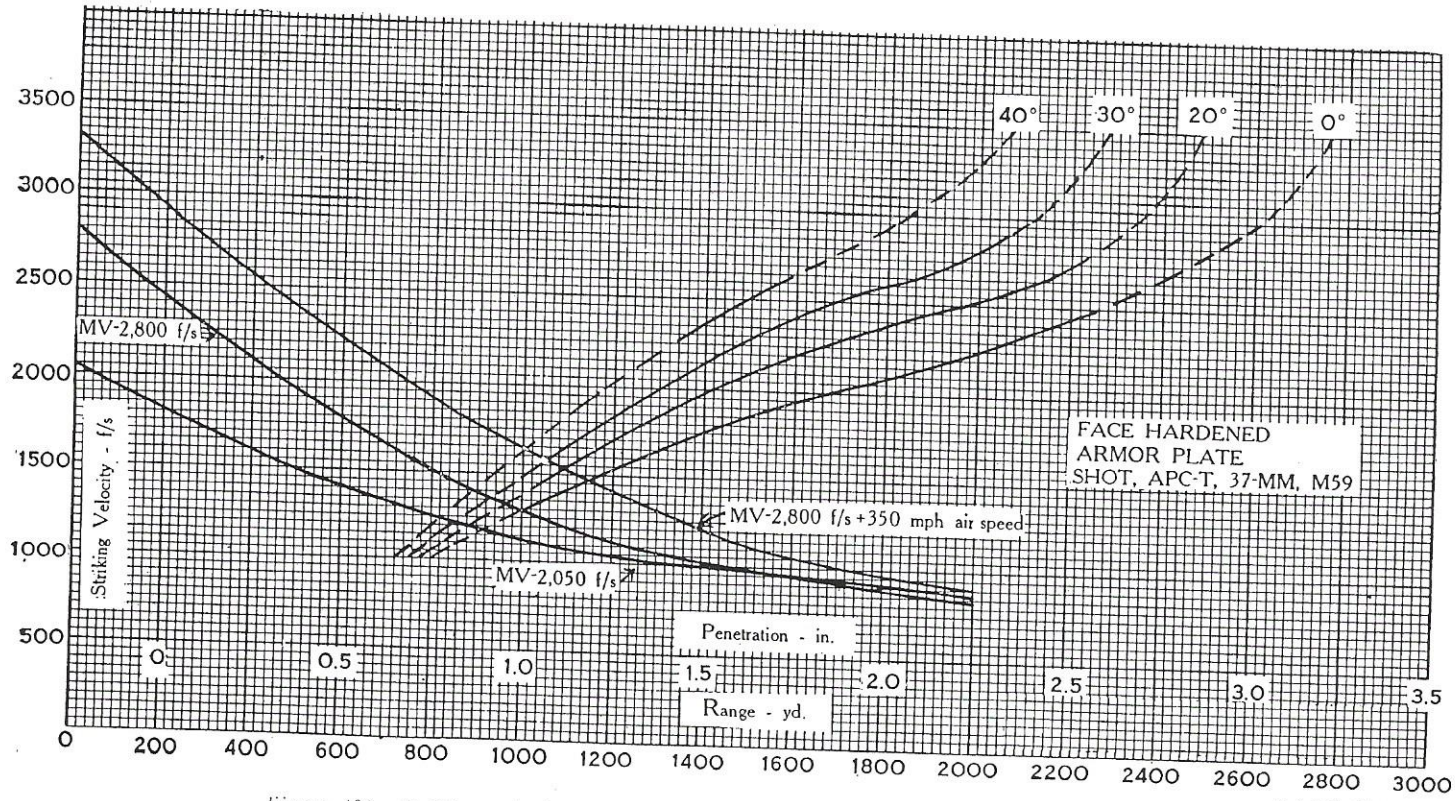


Figure 106. Striking velocity vs armor penetration and range—37-mm APC-T shot M59.

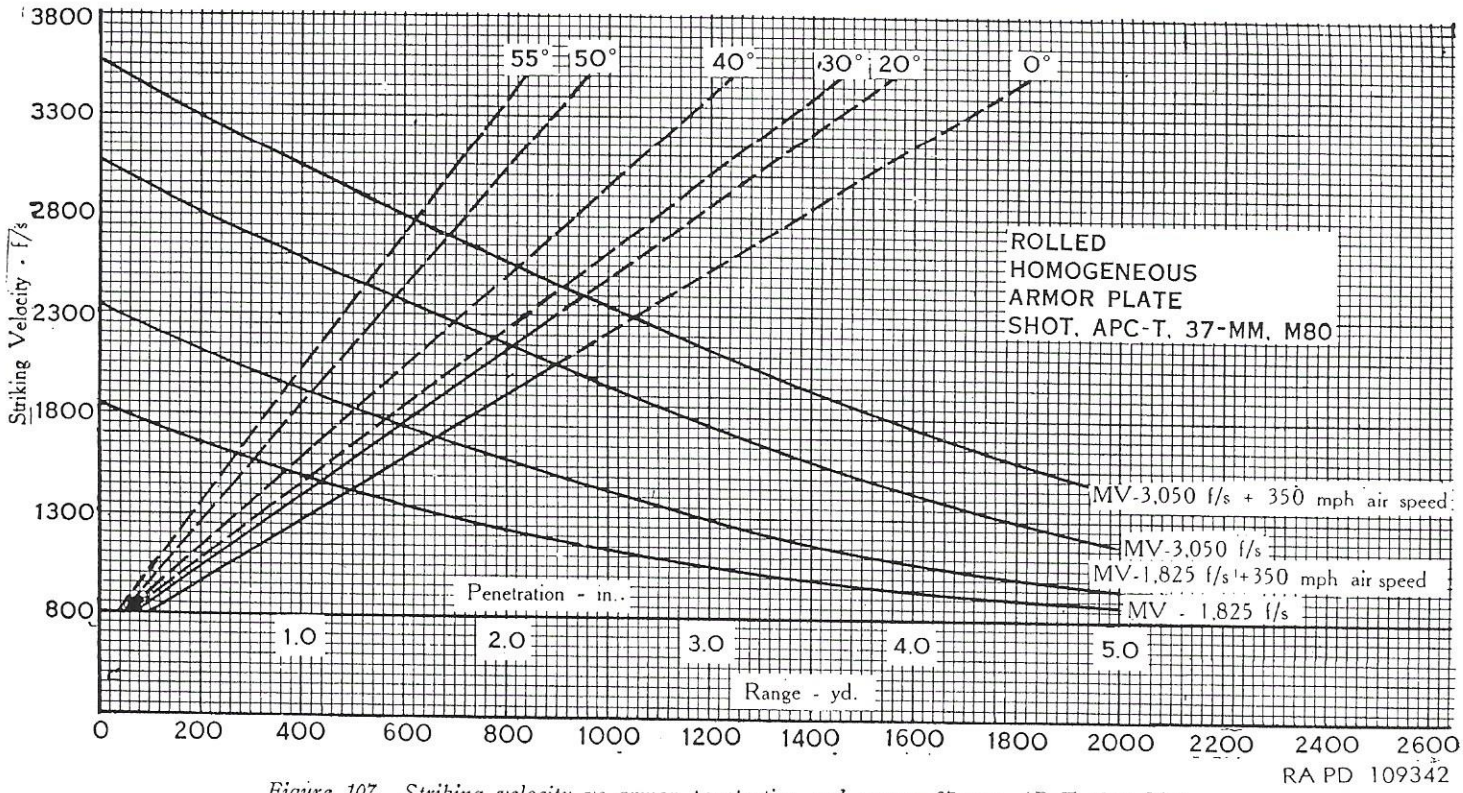


Figure 107. Striking velocity vs armor penetration and range—37-mm AP-T shot M80.

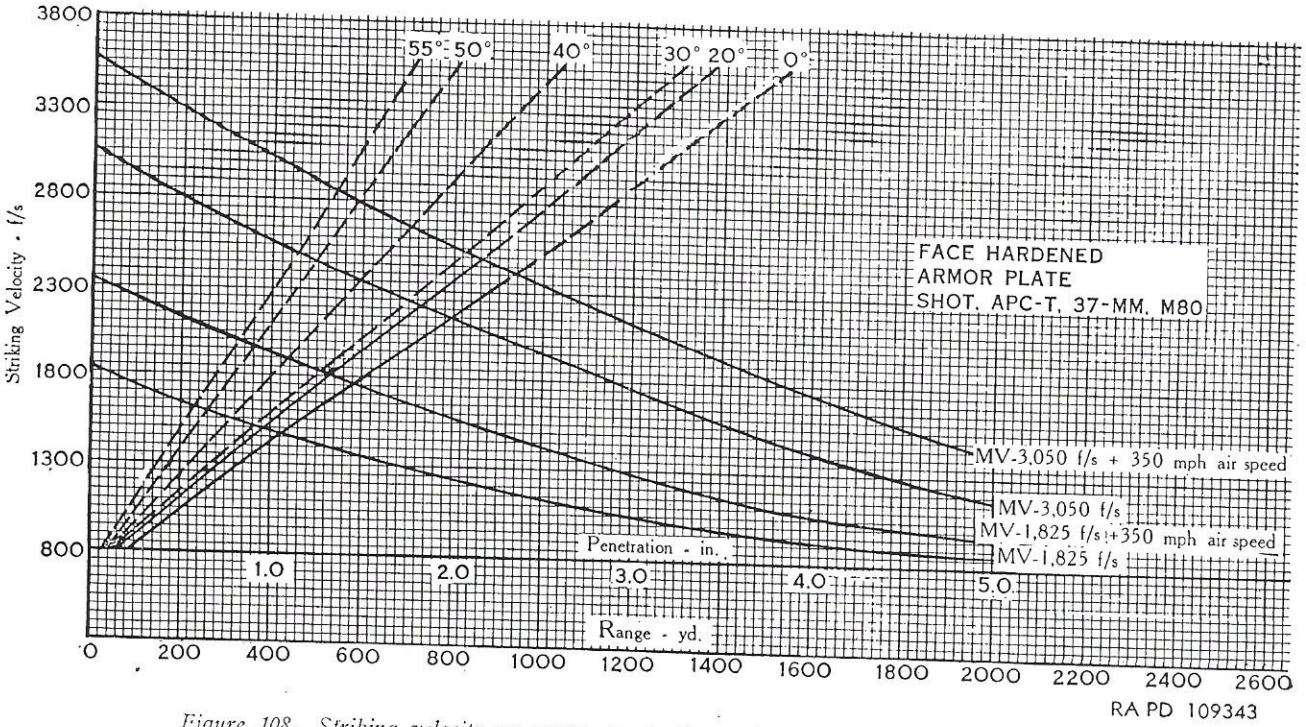


Figure 108. Striking velocity vs armor penetration and range—37-mm AP–T shot M80.

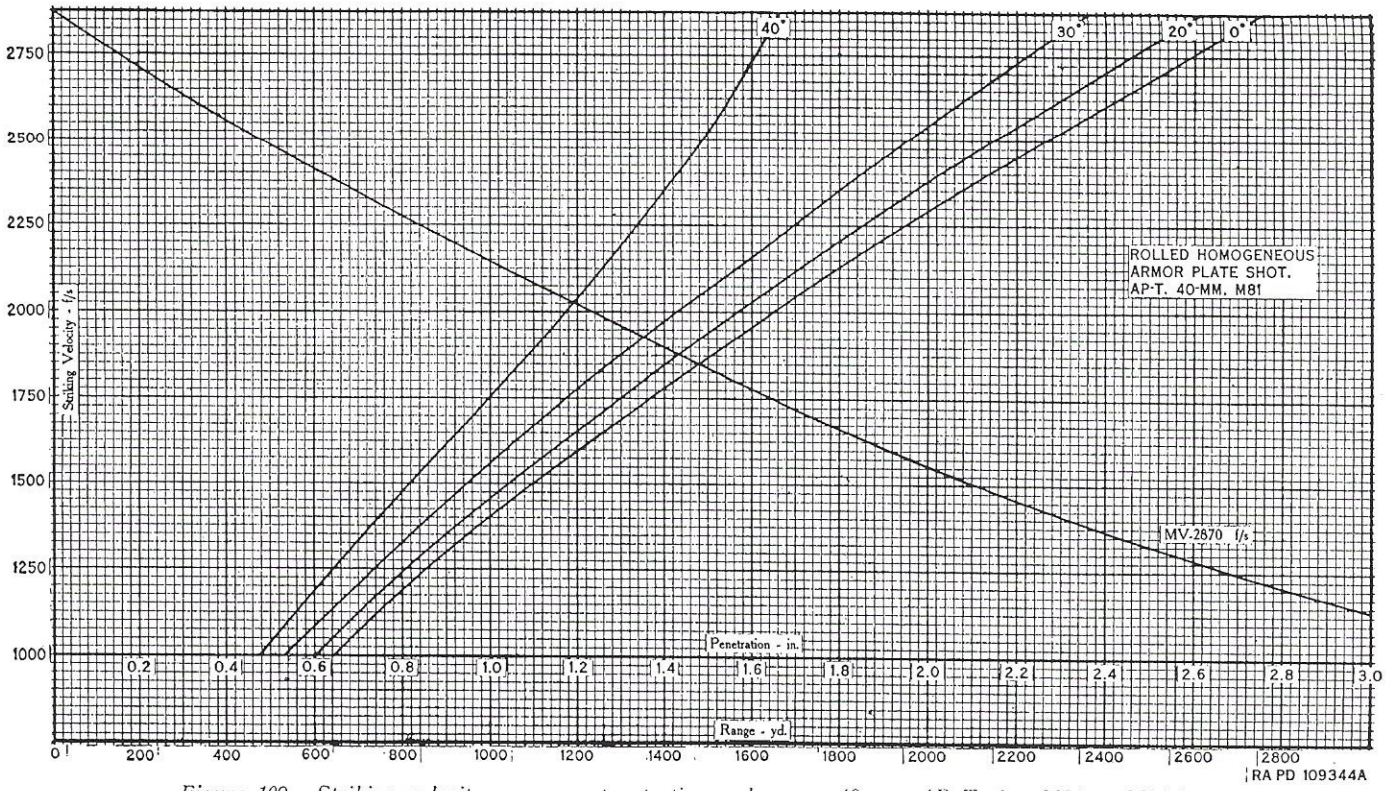


Figure 109. Striking velocity vs armor penetration and range—40-mm AP–T shot M81 or M81A1.

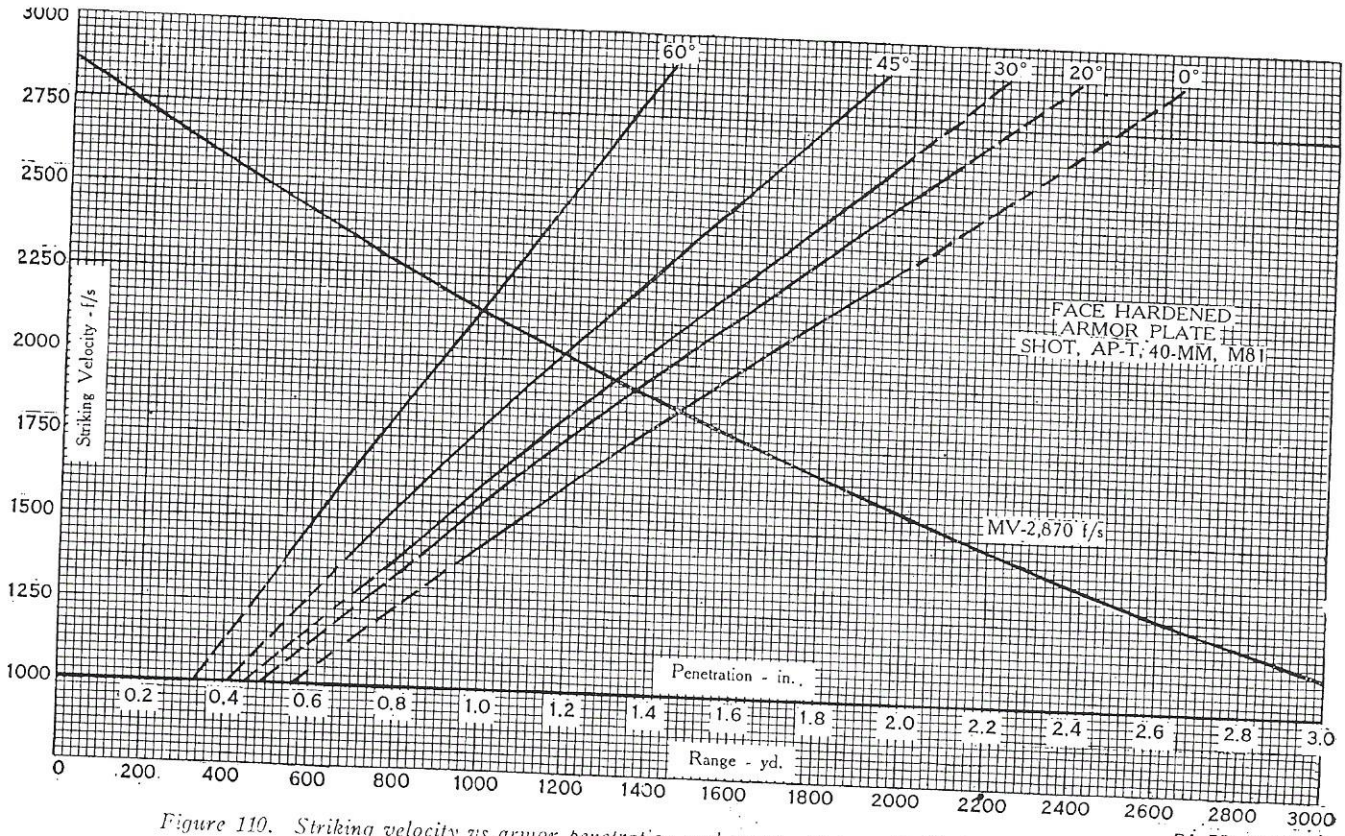


Figure 110. Striking velocity vs armor penetration and range—40-mm AP-T shot M81 or M81A1.

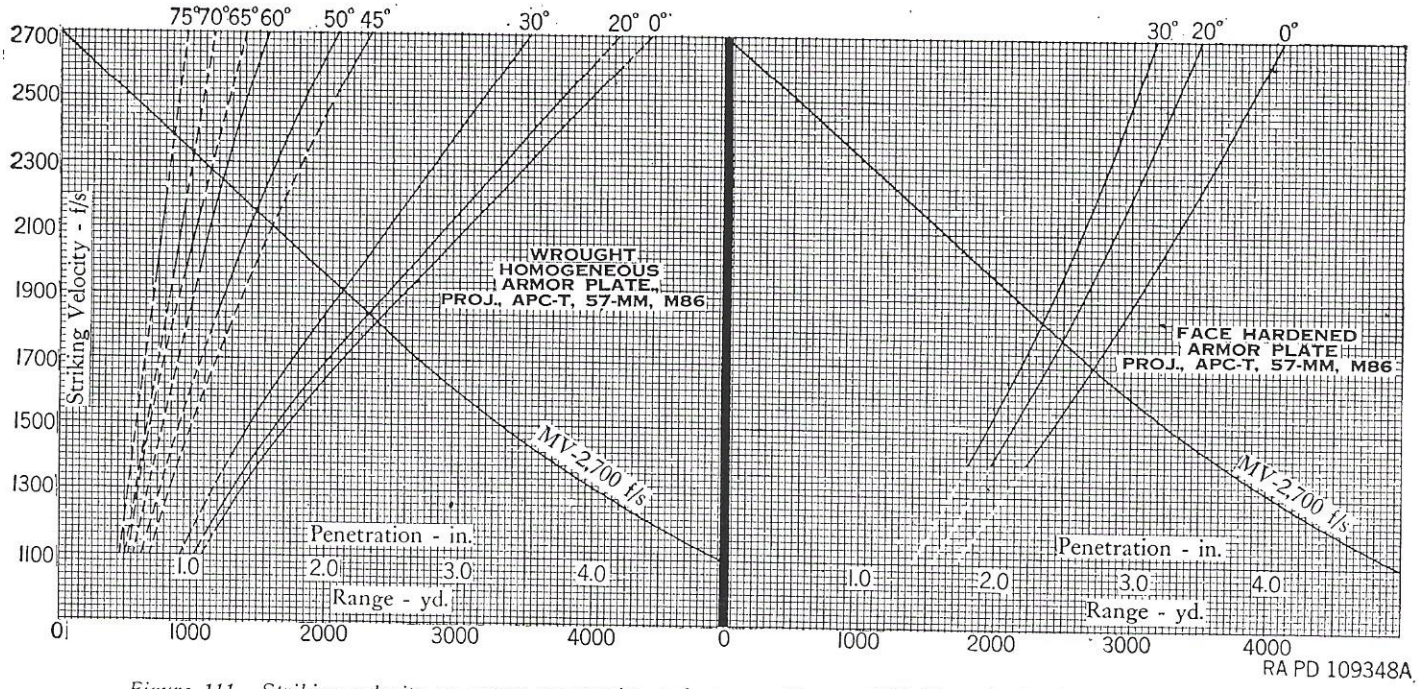


Figure 111. Striking velocity vs armor penetration and range— 57-mm APC-T projectile M86 w/fuze, BD, M72.

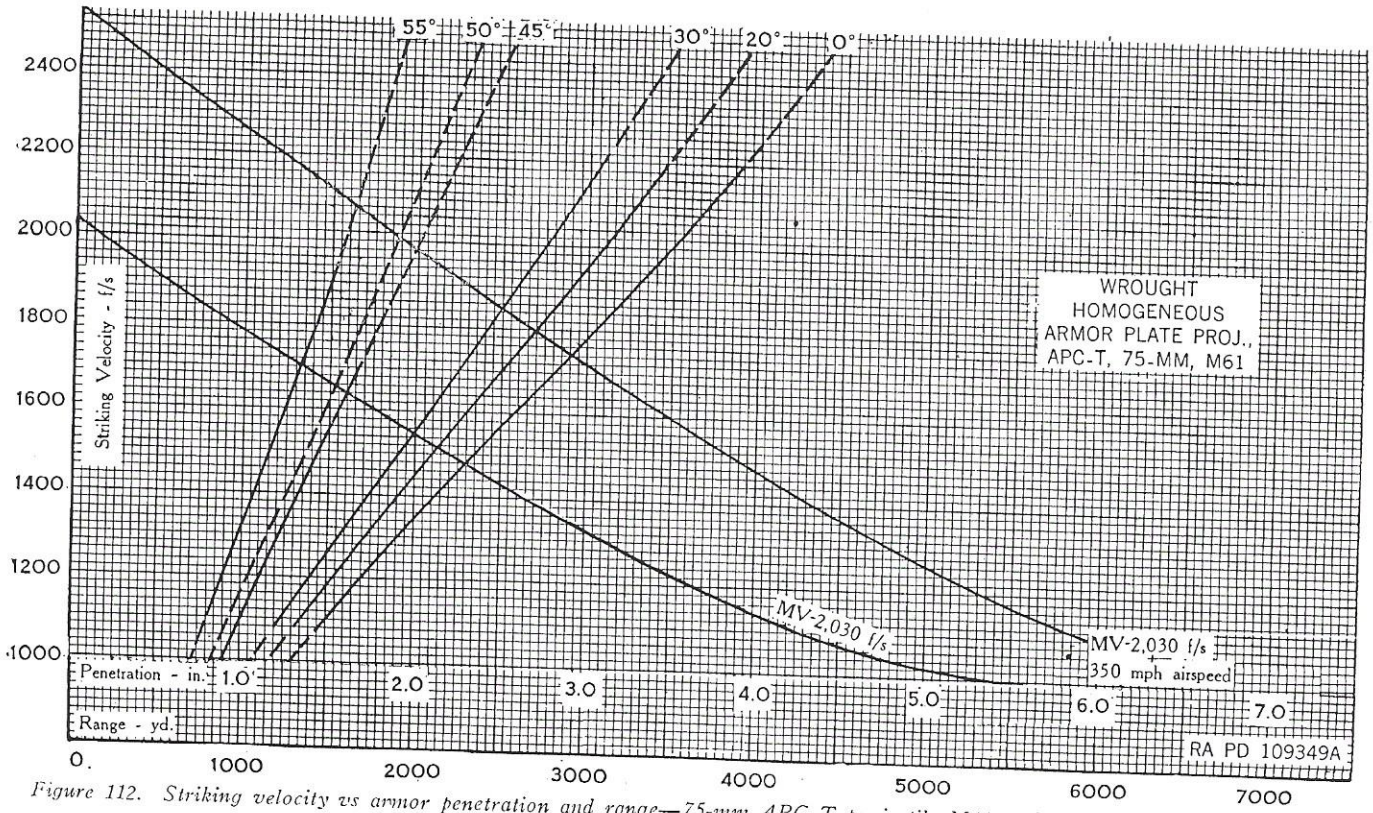


Figure 112. Striking velocity vs armor penetration and range—75-mm APC-T projectile M61 or M61A1 w/fuze, BD, M66A1.

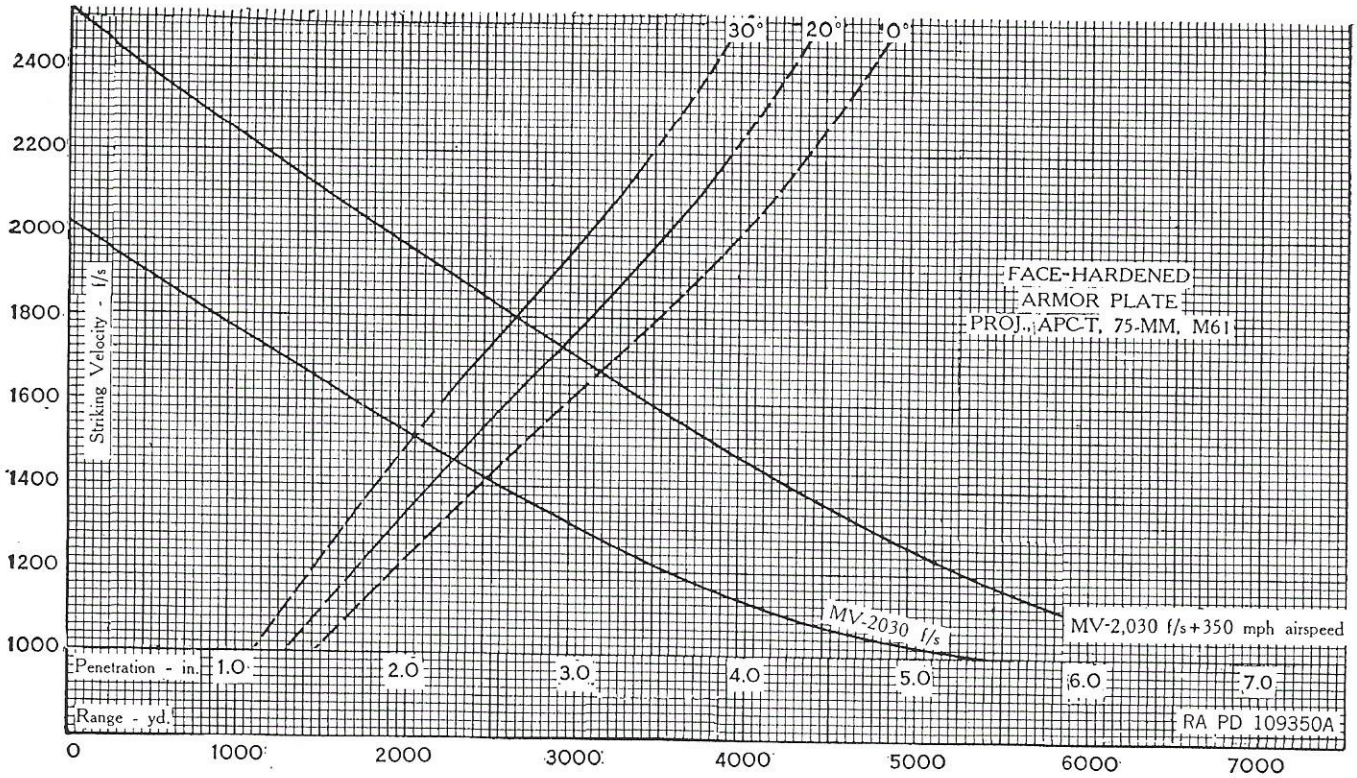


Figure 113. Striking velocity vs armor penetration and range—75-mm APC-T projectile M61 or M61A1 w/fuze, BD, M66A1.

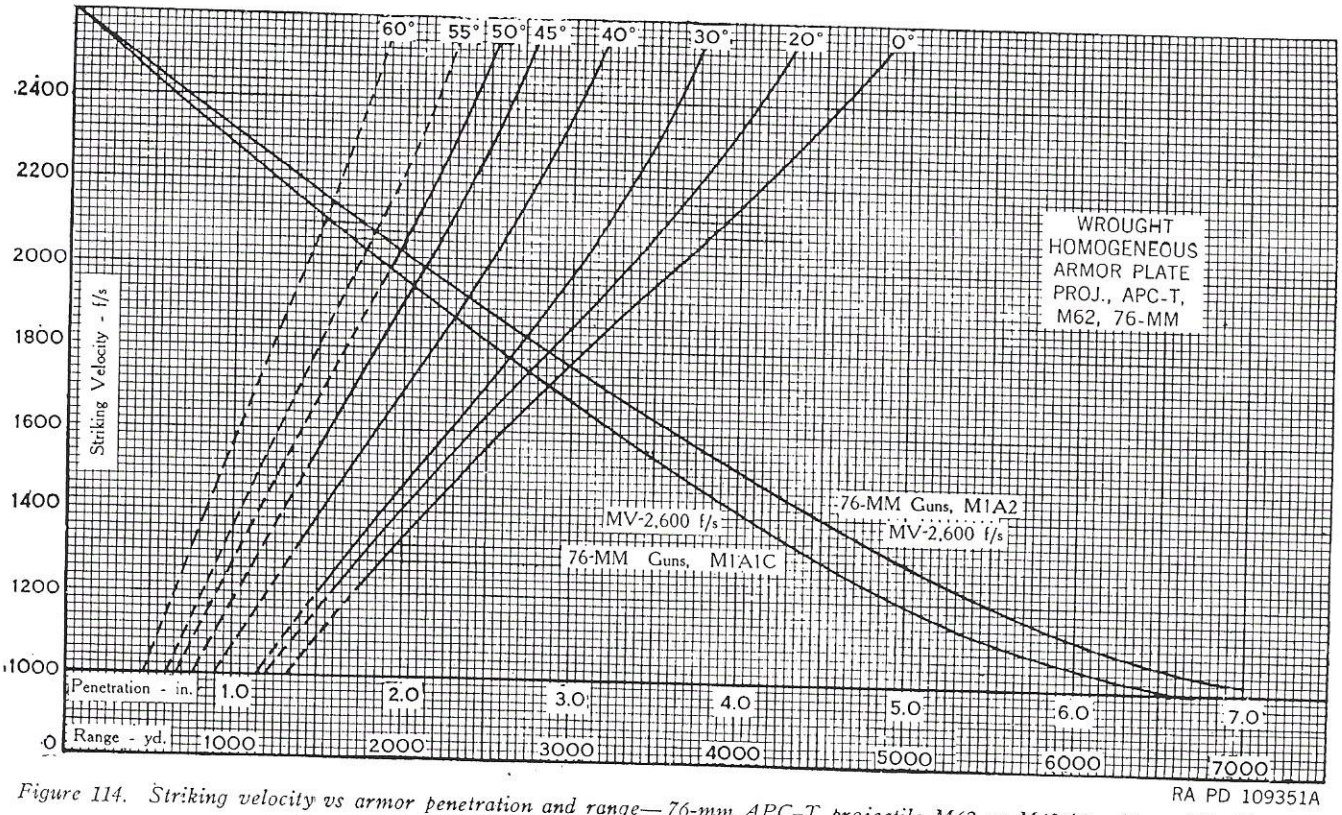


Figure 114. Striking velocity vs armor penetration and range—76-mm APC-T projectile M62 or M62A1 w/fuze, BD, M66A1.

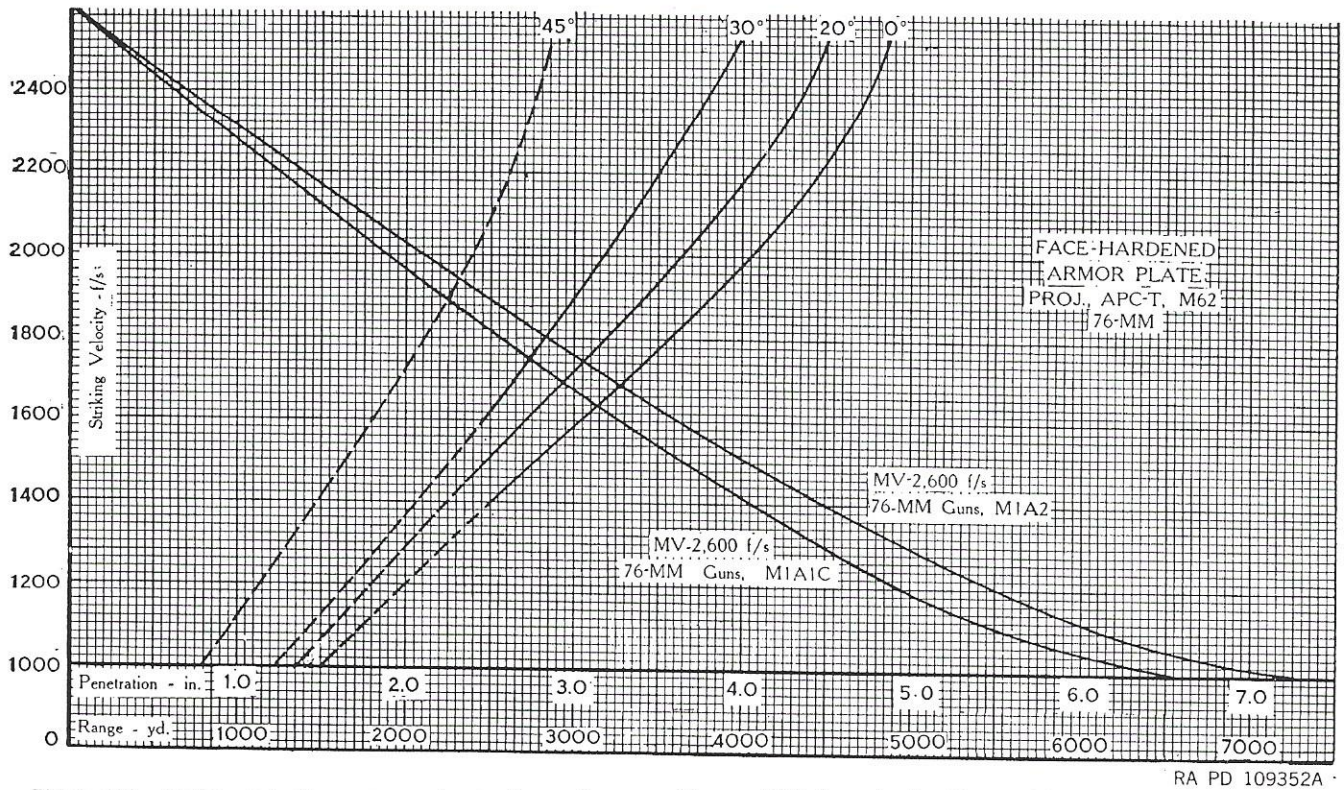


Figure 115. Striking velocity vs armor penetration and range—76-mm APC-T projectile M62 or M62A1 w/fuze, BD, M66A1.

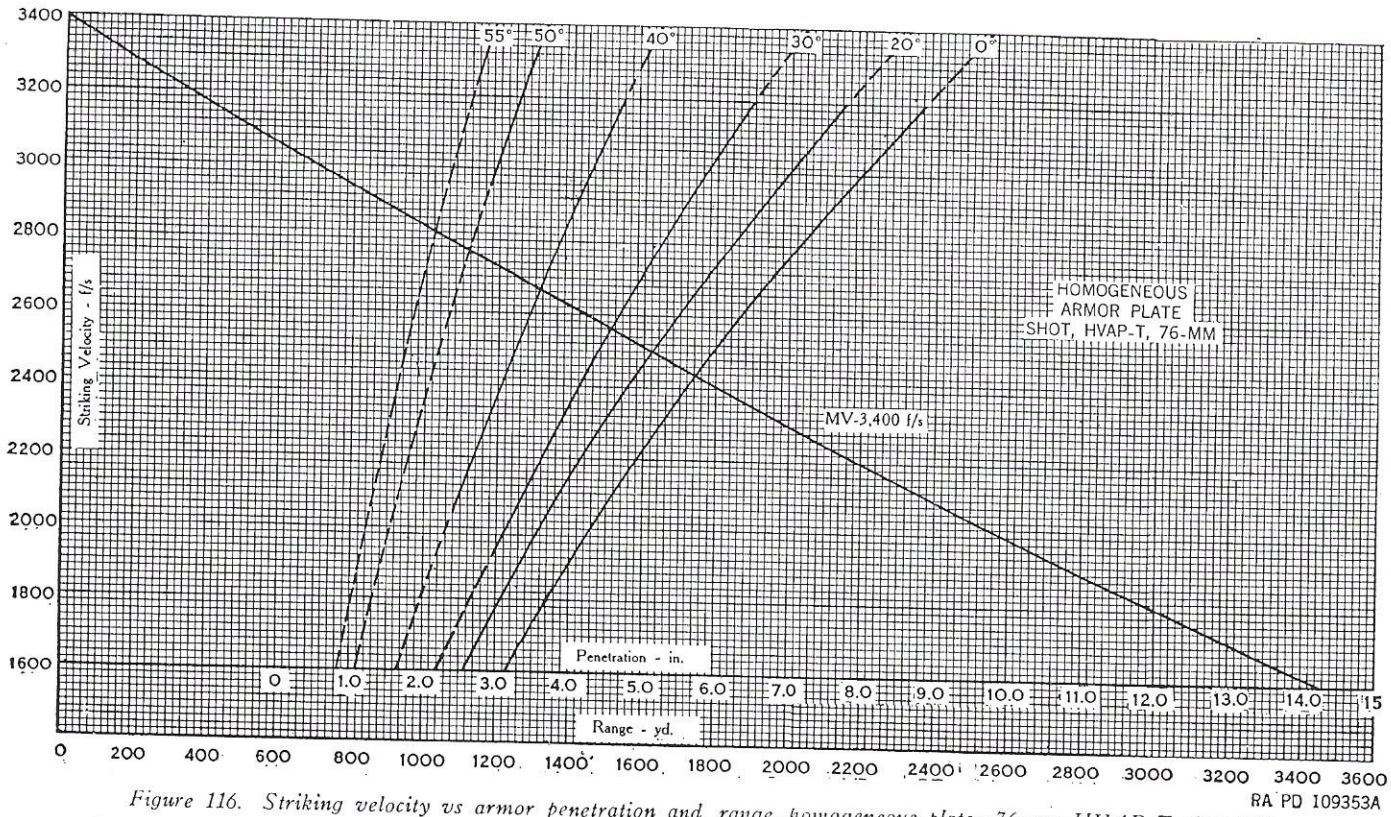


Figure 116. Striking velocity vs armor penetration and range, homogeneous plate—76-mm HVAP-T shot M93.

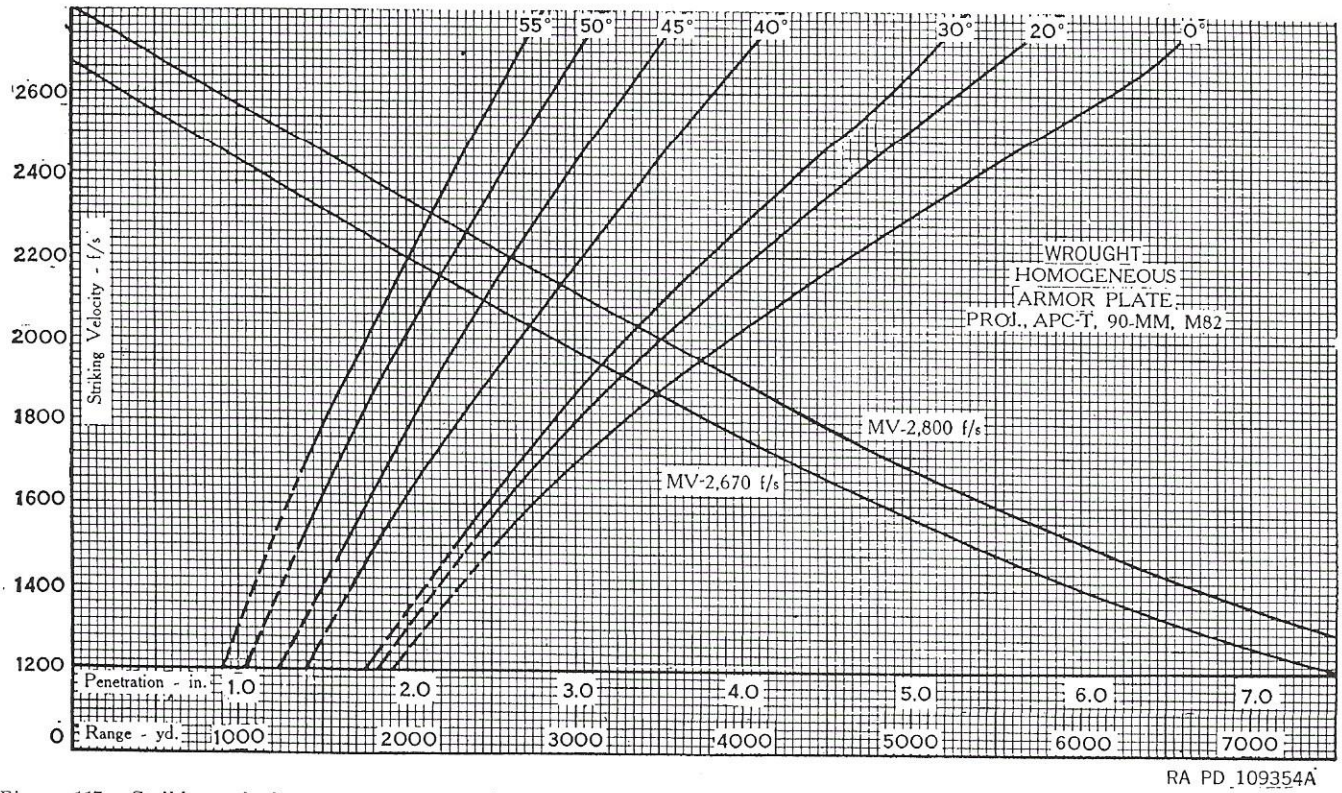


Figure 117. Striking velocity vs armor penetration and range, homogeneous plate— 90-mm APC-T projectile M82 w/fuze, BD, M68.

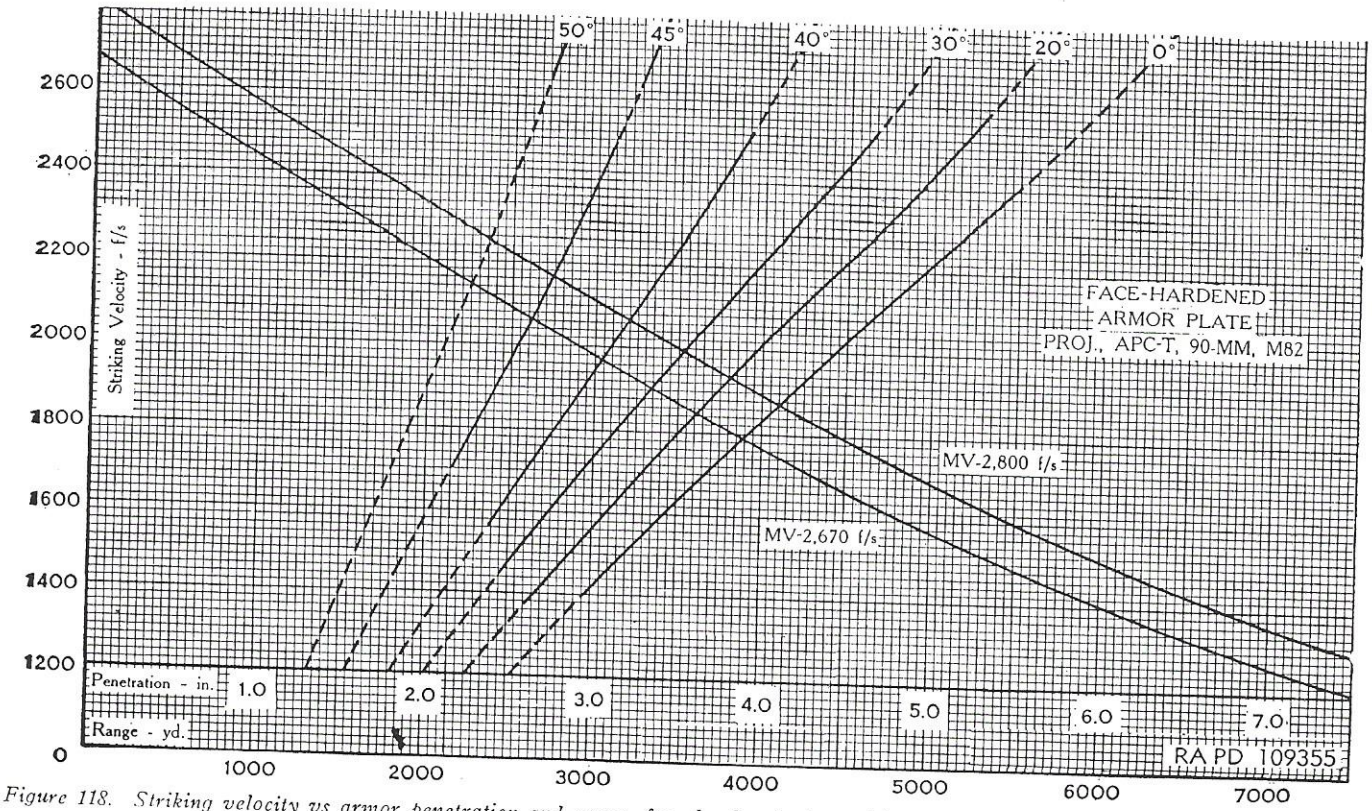


Figure 118. Striking velocity vs armor penetration and range, face hardened plate—90-mm APC-T projectile M82 w/fuze, BD, M68.

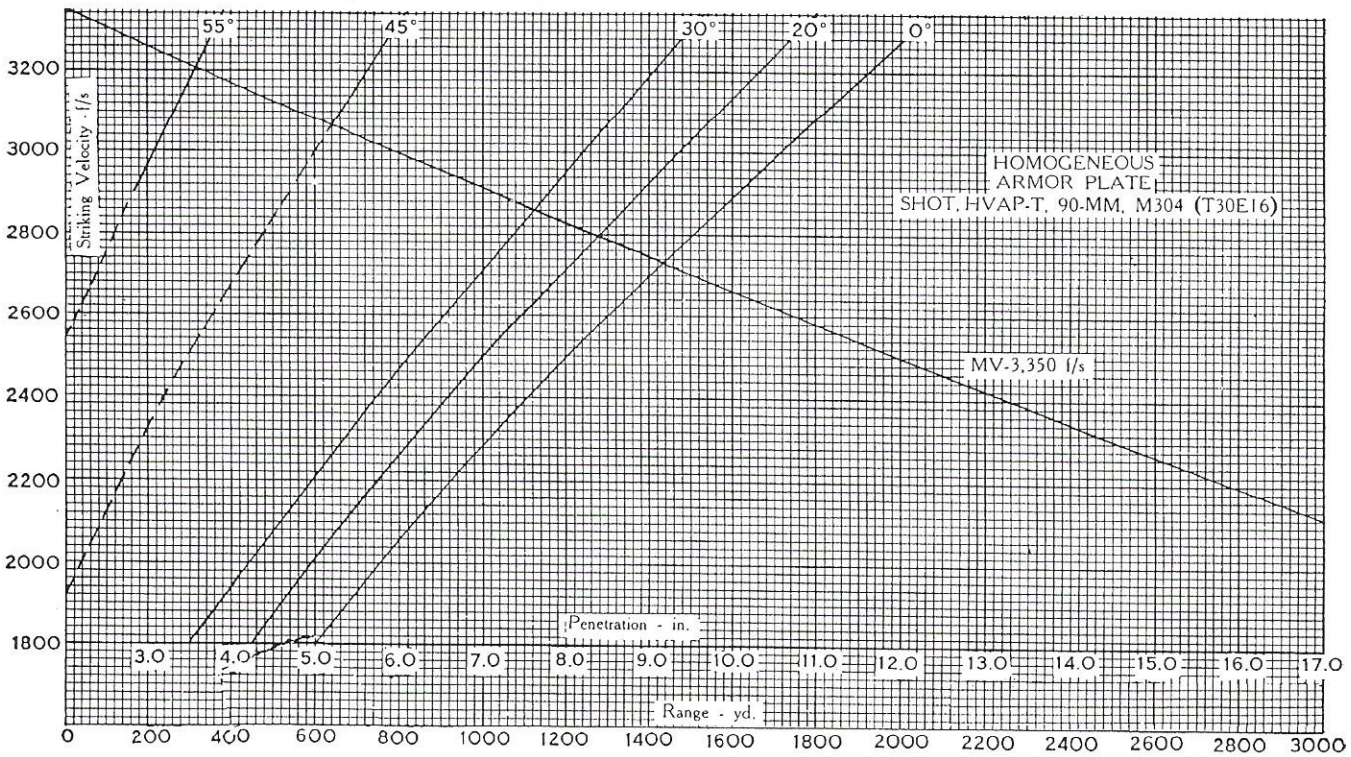


Figure 119. Striking velocity vs armor penetration and range—90-mm HVAP-T shot M304.

penetrate 3 inches of plate, and the maximum range at which the projectile will penetrate the plate is 1,430 yards.

c. EXAMPLE 2. (1) *Given.* 1,430-yard range.

(2) *Required.* The maximum thickness of armor plate which can be penetrated at 20-degree obliquity and the corresponding striking velocity required.

(3) *Solution.* (*a*) Enter the scale at 1,430 yards on D and proceed upward on a vertical line to point C where the striking velocity curve is intersected.

(*b*) Proceed right from C along a horizontal line to B where the penetration curve for 20-degree obliquity is intersected.

(*c*) Then proceed downward along a vertical line to A where a thickness of 3 inches is read.

(*d*) From point C proceed left along horizontal line to E where a striking velocity of 2,160 feet per second is read.

d. EXAMPLE 3. (1) *Given.* 2,160 feet per second striking velocity.

(2) *Required.* The range and thickness of 20-degree obliquity armor plate which can be penetrated.

(3) *Solution.* (*a*) Enter the striking velocity scale at point E which represents 2,160 feet per second.

(*b*) Proceed right to point C and then downward along the vertical line to D where the range of 1,430 yards can be read.

(*c*) From point C proceed right to B on the 20-degree obliquity curve and then downward along the vertical line to A where the thickness of 3 inches can be read.

Section V. ARTILLERY ATTACK ON CONCRETE

77. Definitions

a. PENETRATION AND PERFORATION. The following considerations, as used in discussion, tables, and charts, apply to attack on concrete targets. *Perforation* of a concrete target, wall, or roof, means making a hole all the way through. *Penetration* means making a crater which does not go all the way through. *Depth of penetration* is measured perpendicular to the face of the wall.

b. EDGE EFFECT. When the target is sufficiently close to have small dispersion of fire the artilleryman can make use of the edge effect under some conditions. Projectiles striking closer than 15 calibers from the edge of a wall (an embrasure usually) penetrate more deeply and remove more concrete than if striking in the center. The effect is marked at 10 calibers from the edge and best at about 8 calibers. Up to double the normal volume of concrete for each round may be removed by the use of edge effect.

78. Single Perforations

The charts and tables in this section are based on the following hypotheses—

a. That data shown are based on firing against the center of a wall without consideration of edge effect.

b. Although the penetration decreases with the obliquity of the target, the crater produced is wider than that produced by normal impact. The actual volume of concrete removed per round may even increase for oblique impact. For prolonged fire, the obliquity probably does not greatly influence the number of rounds necessary to obtain perforation, up to obliquities of 20 degrees to 30 degrees.

c. Heavier targets must, in general, be defeated by repeated fire, perforation finally being obtained by having several rounds hit in approximately the same small area. The number of hits in the same crater necessary for perforation increases with range, and the chance of obtaining multiple hits in the same small area decreases with range; therefore, the total number of rounds which must be fired to have a high probability of perforation increases very rapidly with range to enormous values at the higher ranges.

d. Data in the charts and tables are calculated by estimating, at the given range, the number of consecutive hits in one small crater necessary to perforate and, from the range table probable errors, the number of rounds which must be fired to obtain this number of hits in this crater. The tables should be of value in determining approximately, at least, the ranges at which various weapons will be effective and for obtaining some comparison between the different weapons. The absolute numbers must be accepted with some caution since other factors such as age of gun and stability of emplacement will affect the number of rounds required.

e. Especially when the table entry is large (100 or over) there should be a fair fraction of perforation from all subsequent hits. In short, the entries in the table should not be far below the number of rounds necessary to obtain complete destruction of the target, except in the case of small calibers at close range.

f. The data for the high-explosive shell with CP fuze M78 (0.025 sec. delay) is probably pessimistic, as the high-explosive shell with this fuze removes greater volumes of concrete than the armor-piercing projectiles. For multiple hits, all other factors being equal, the destructive effect of the high-explosive shell with this fuze is greater than that produced by armor-piercing projectiles.

79. Breaching a Concrete Wall

The following considerations should be kept in mind when attempting to breach a concrete wall:

a. Various factors such as amount of reinforcing, compressive strength of concrete, size of aggregate, and use of "plums" (boulders set in the concrete to save material) will affect the number of hits necessary to breach a wall. Such factors as age of gun, stability of carriage emplacement, and experience of the gunner in this type of fire also will affect the number of rounds.

b. Concerning the use of the entries when the probable errors are not those of the range table, the same cautions apply, but with less emphasis, as in the discussion of single perforations (par. 78*d*).

c. It is recommended that the target be taken initially about 3 feet below the top of the wall (perhaps 2 feet for projectiles of caliber 90-mm or less), and lowered as successive rounds are fired and the breach deepens.

d. It is necessary to cut a breach about 6 feet deep from the top in a wall 10 feet thick; and 7 feet deep in a wall 6 feet thick. There should be a ramp of rubble in front of the breach. (If fire is continued too long, the material of the ramp will be of too fine mesh to give good traction.) The breach will tend to be narrower and not so deep toward the back, and there will be a drop of several feet to the rubble behind the wall. Tests have shown that such a breach will pass a medium tank.

e. Armor-piercing (or armor-piercing-capped) ammunition alone will not make a satisfactory breach in reinforced concrete. The concrete will be removed but twisted reinforcing rods will remain standing. If it is deemed advisable to use armor-piercing rounds against reinforced concrete, a portion (say a fifth) of the number of armor-piercing rounds listed should be replaced with high-explosive shell, superquick fuzed, perhaps of larger caliber and lower velocity. A few rounds of armor-piercing projectile should be followed by one or two of high-explosive shell. The fragments from the high-explosive shell cut the rods. It may be assumed that most concrete is reinforced.

80. Charts and Tables

a. CHARTS. Figures 120 to 136, inclusive, are charts giving the *total number of rounds* necessary at the various ranges to obtain 90 percent probability of at least one perforation in grade A (5,000 pounds per square inch compressive strength) concrete targets of height (H), width (W), and thickness (T) given in the chart.

b. TABLES. (1) Table LII gives total number of rounds and total weight of rounds for various weapons fired at various ranges to have 90 percent probability of at least one perforation of the wall in 3-, 5-, and 7-foot thick concrete pill boxes.

(2) Tables LIII to LXVII give the following data for various projectiles:

(*a*) Projectile weight.

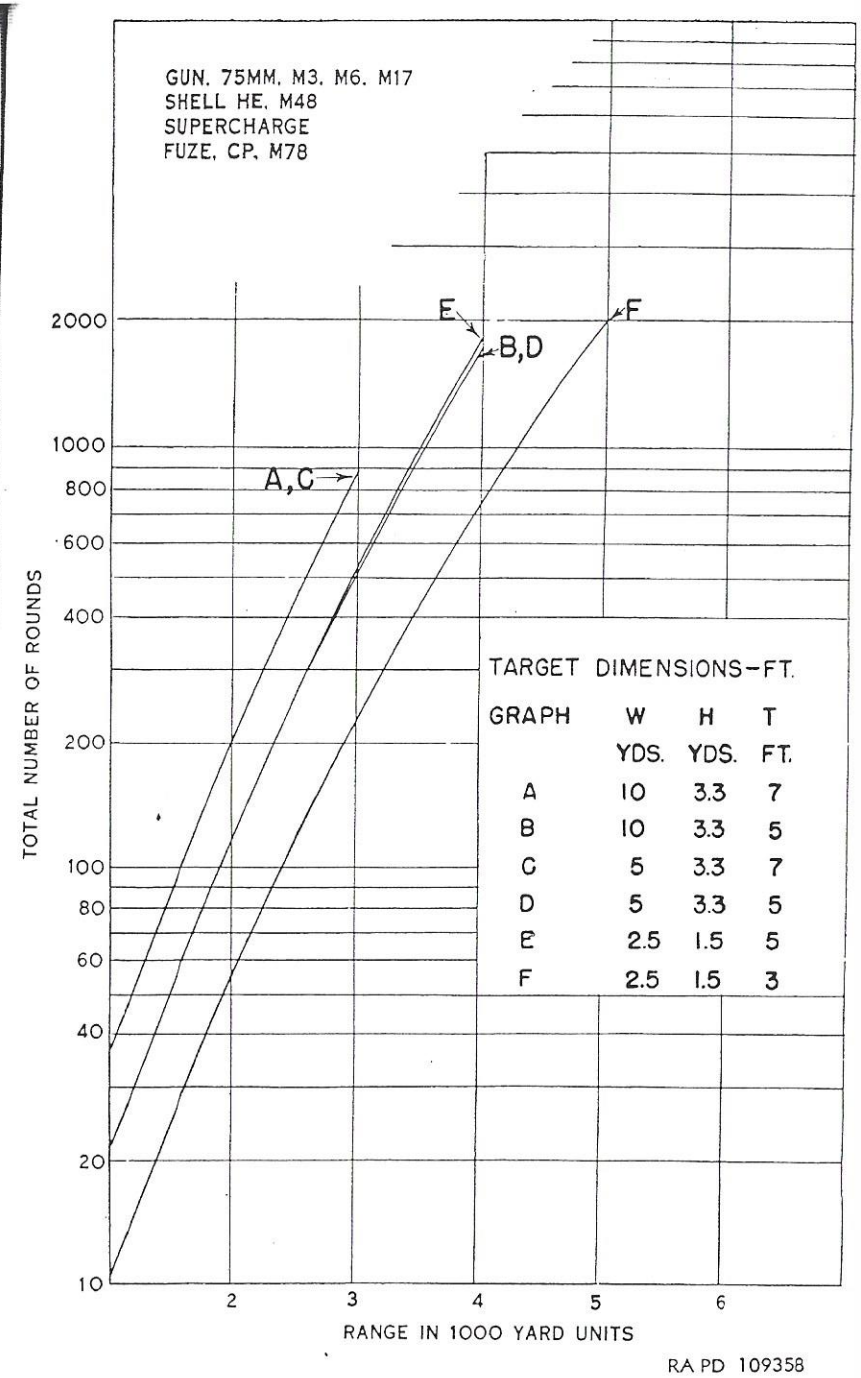


Figure 120. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (75G: HE w/CPF; SC).

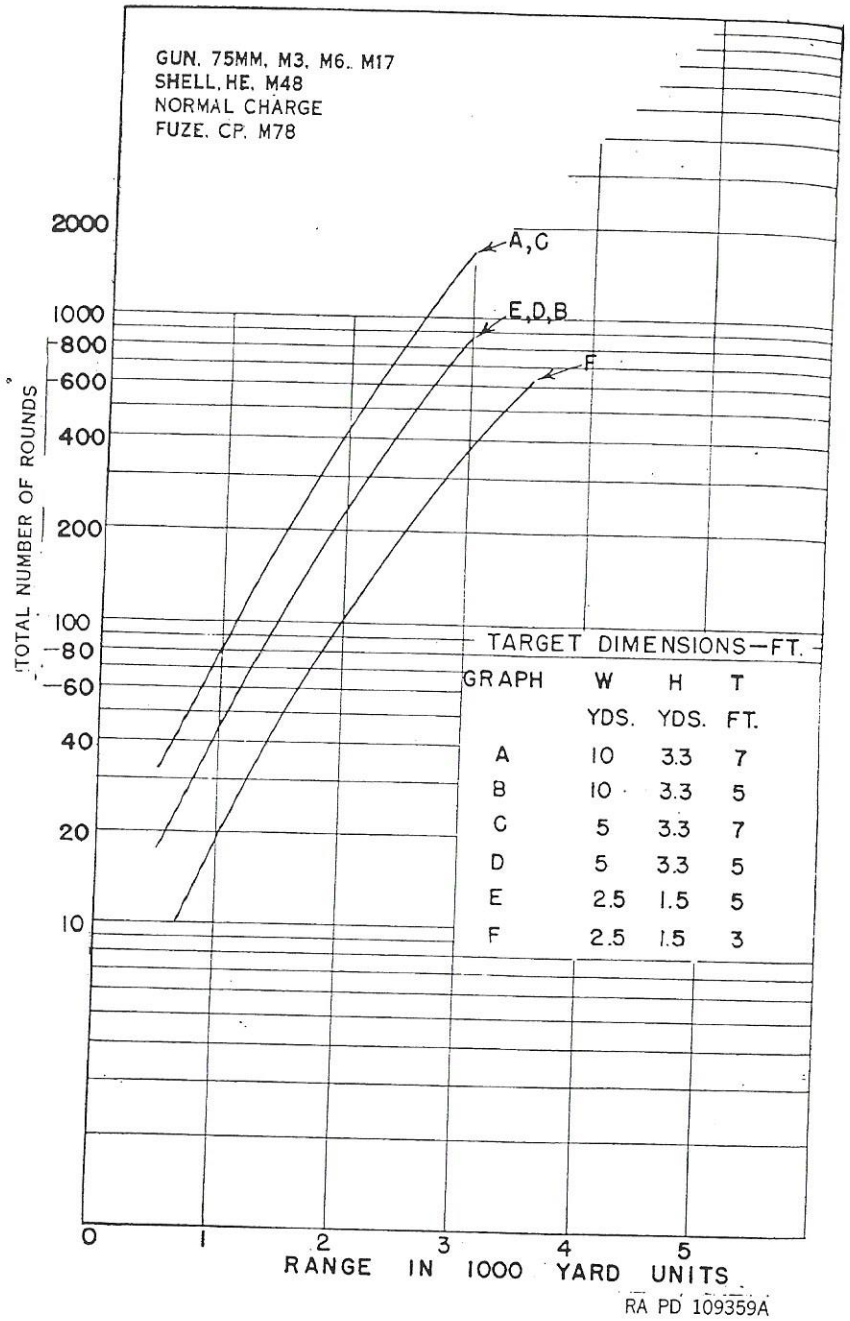


Figure 121. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (75G: HE w/CPF; NC).

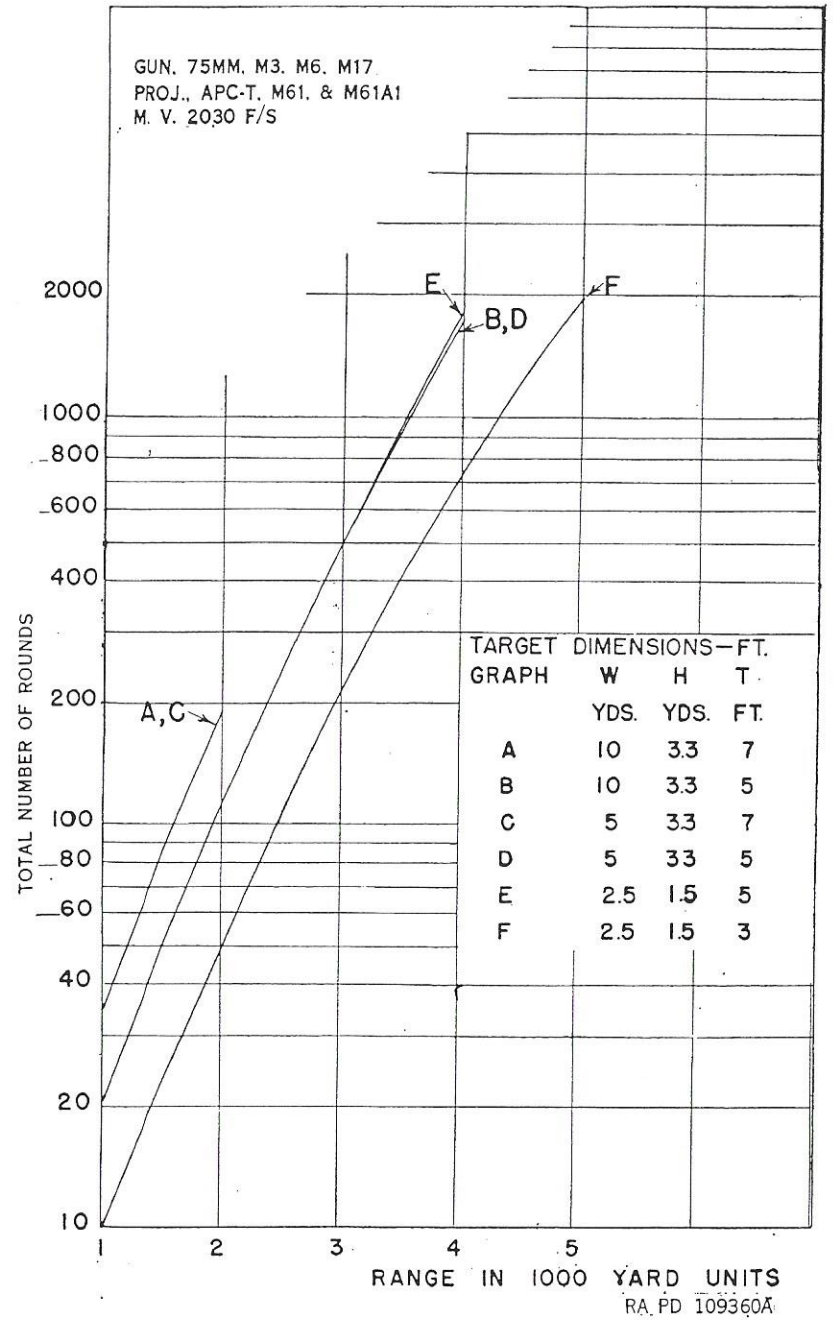


Figure 122. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (75G: APC-T (MV 2030)).

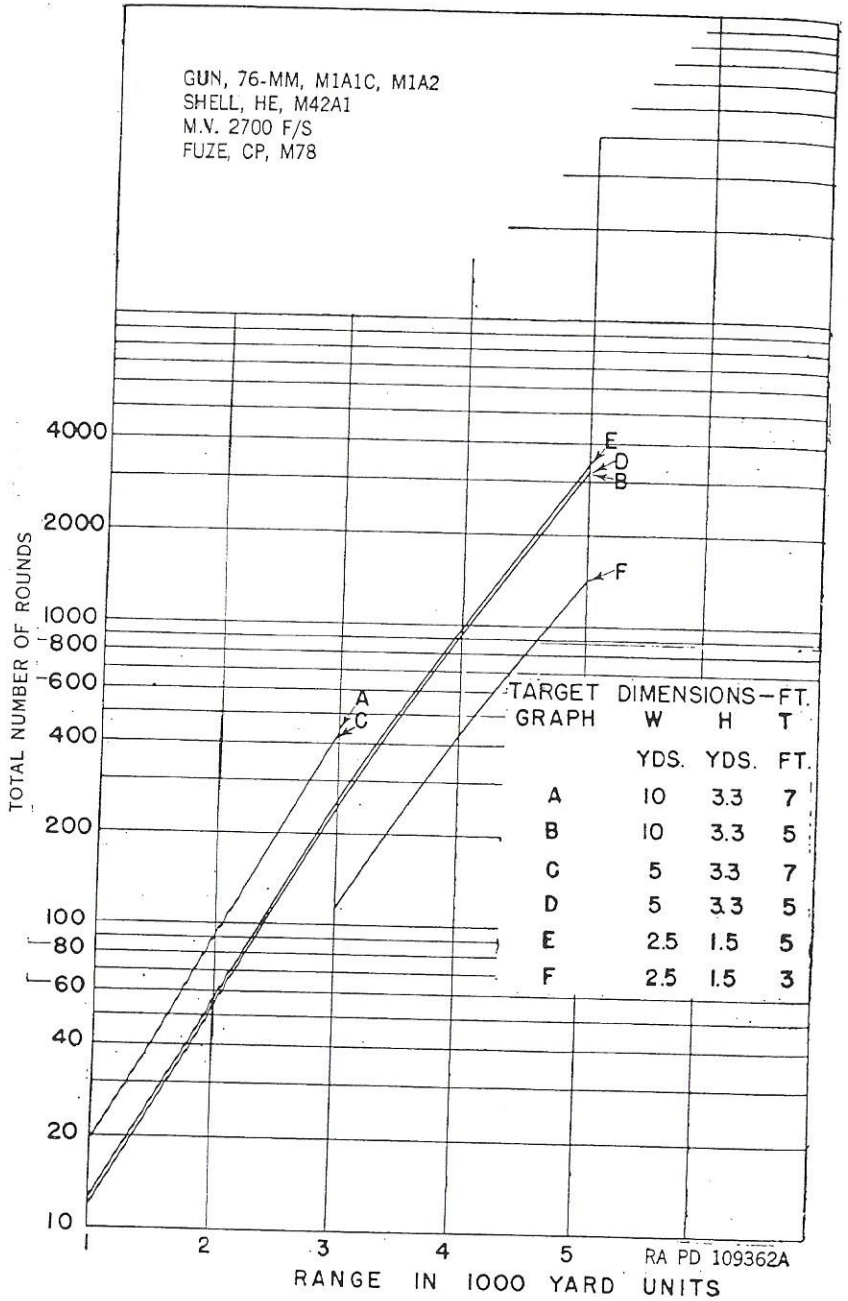


Figure 123. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (76G: HE w/CPF (MV 2700)).

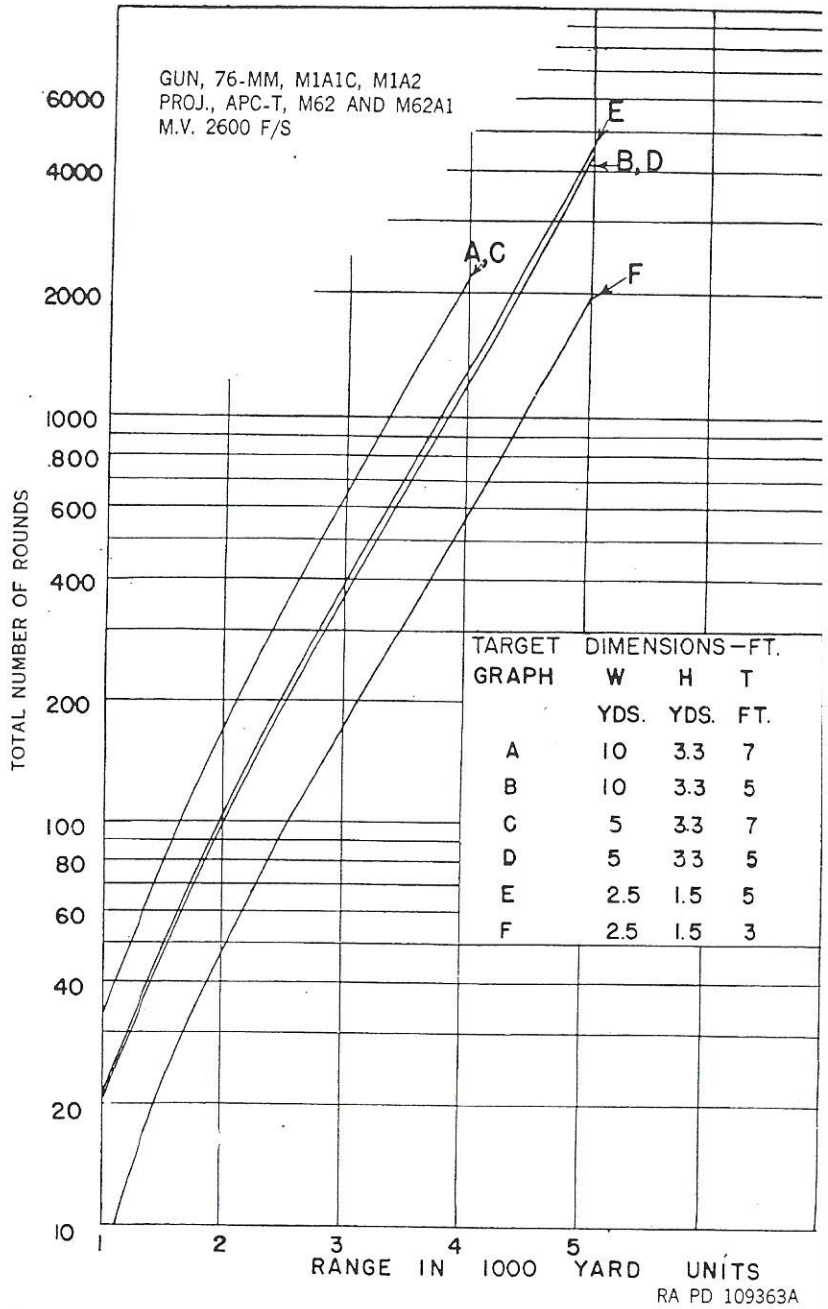


Figure 124. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (76G: APC-T (MV 2600)).

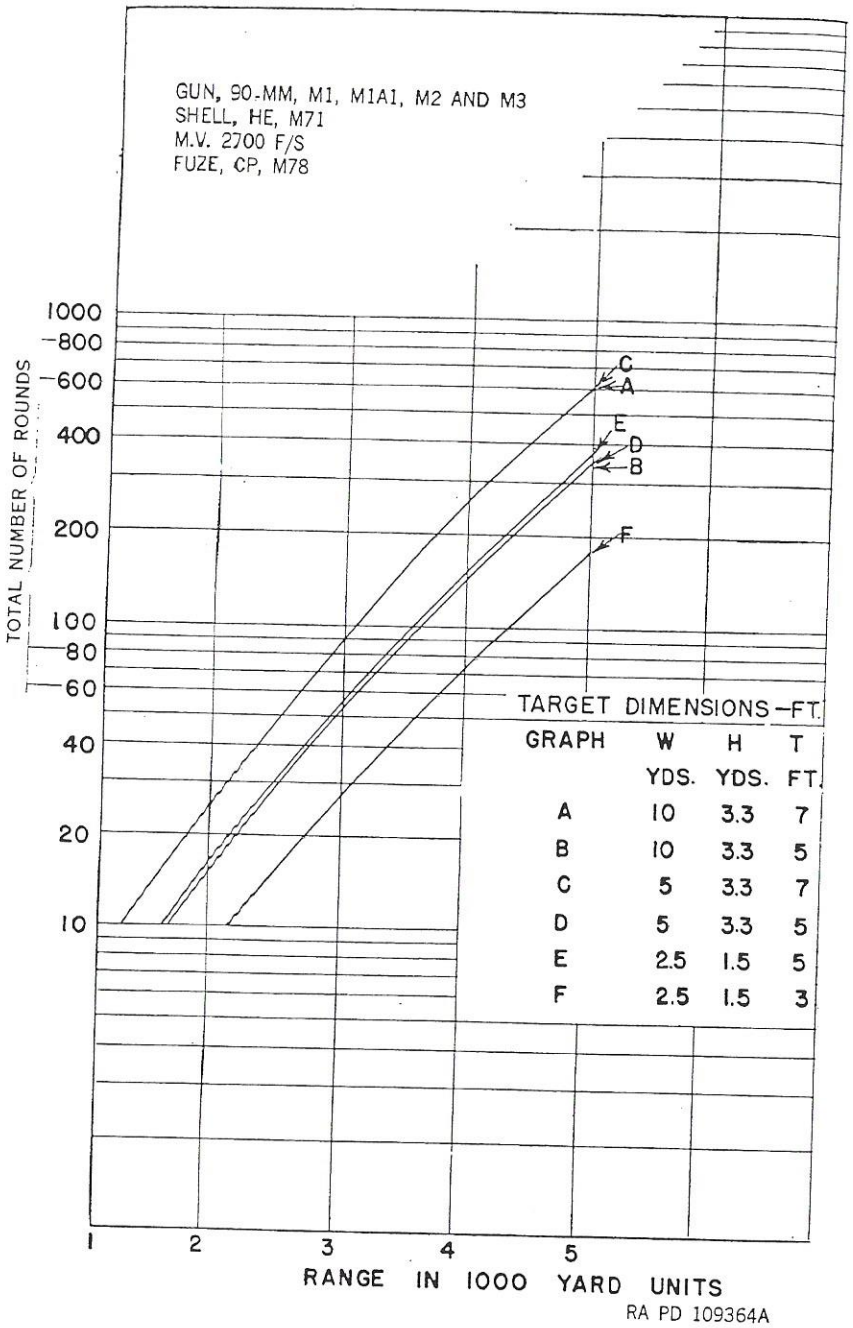


Figure 125. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (90G: HE w/CPF (MV 2700)).

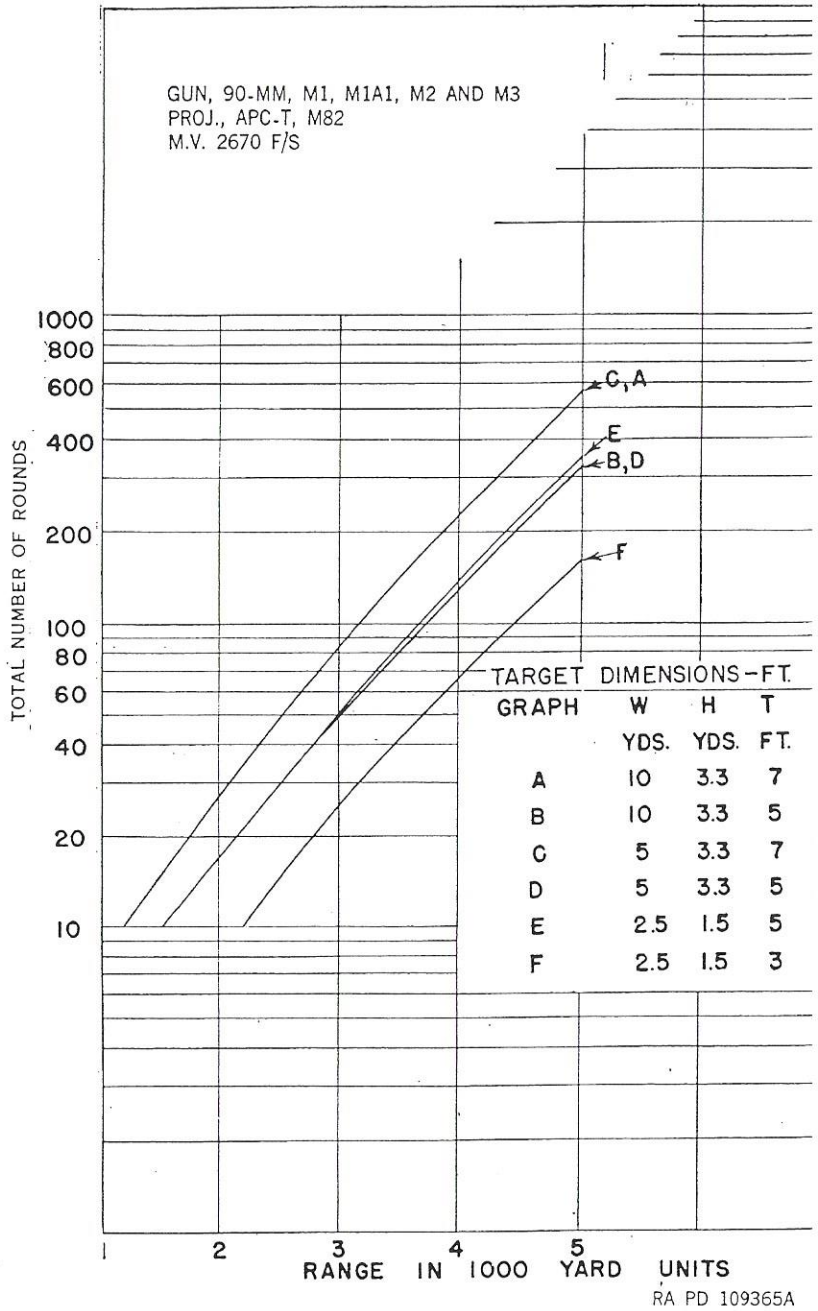


Figure 126. Number of rounds required for single perforation of concrete wal (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (90G: APC-T (MV 2670)).

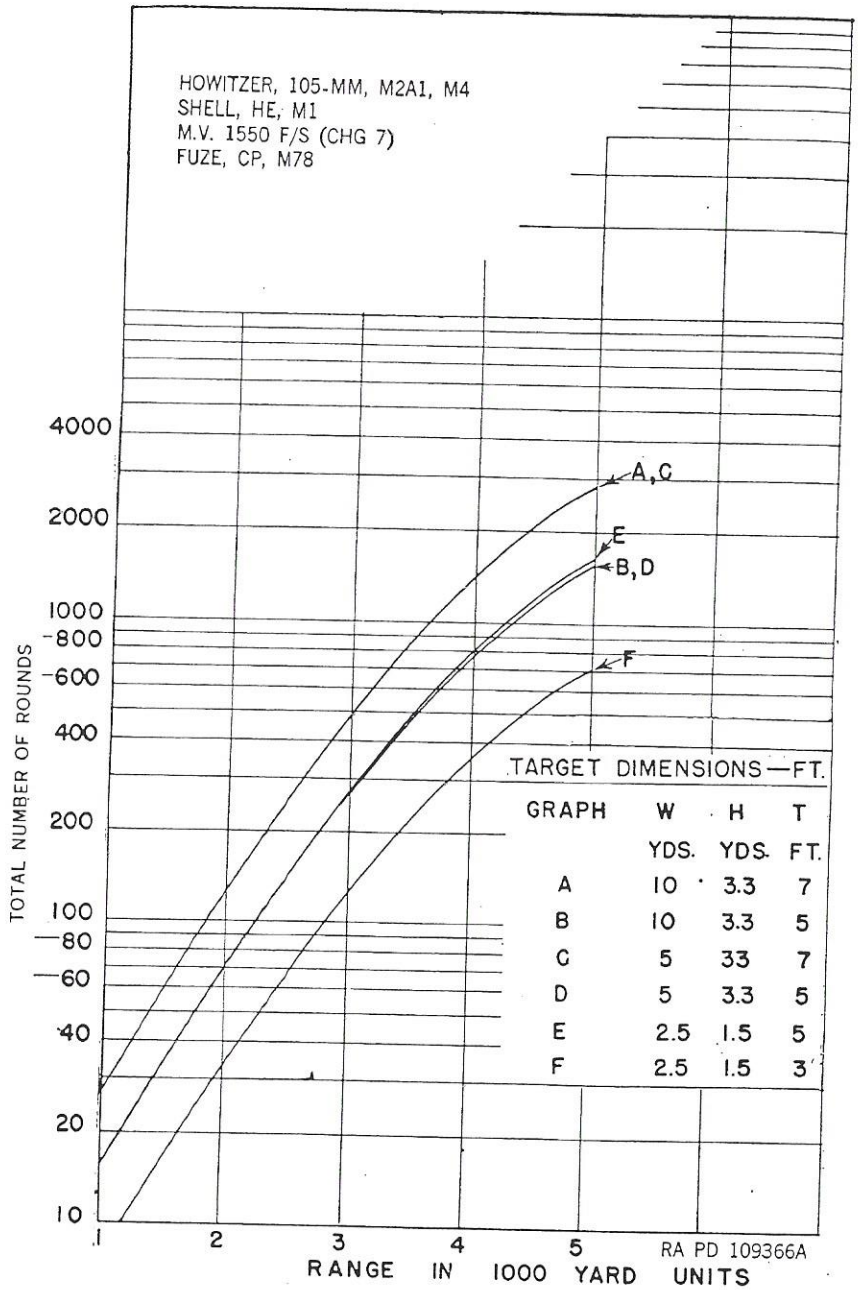


Figure 127. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (105H: HE w/CPF (MV 1550)).

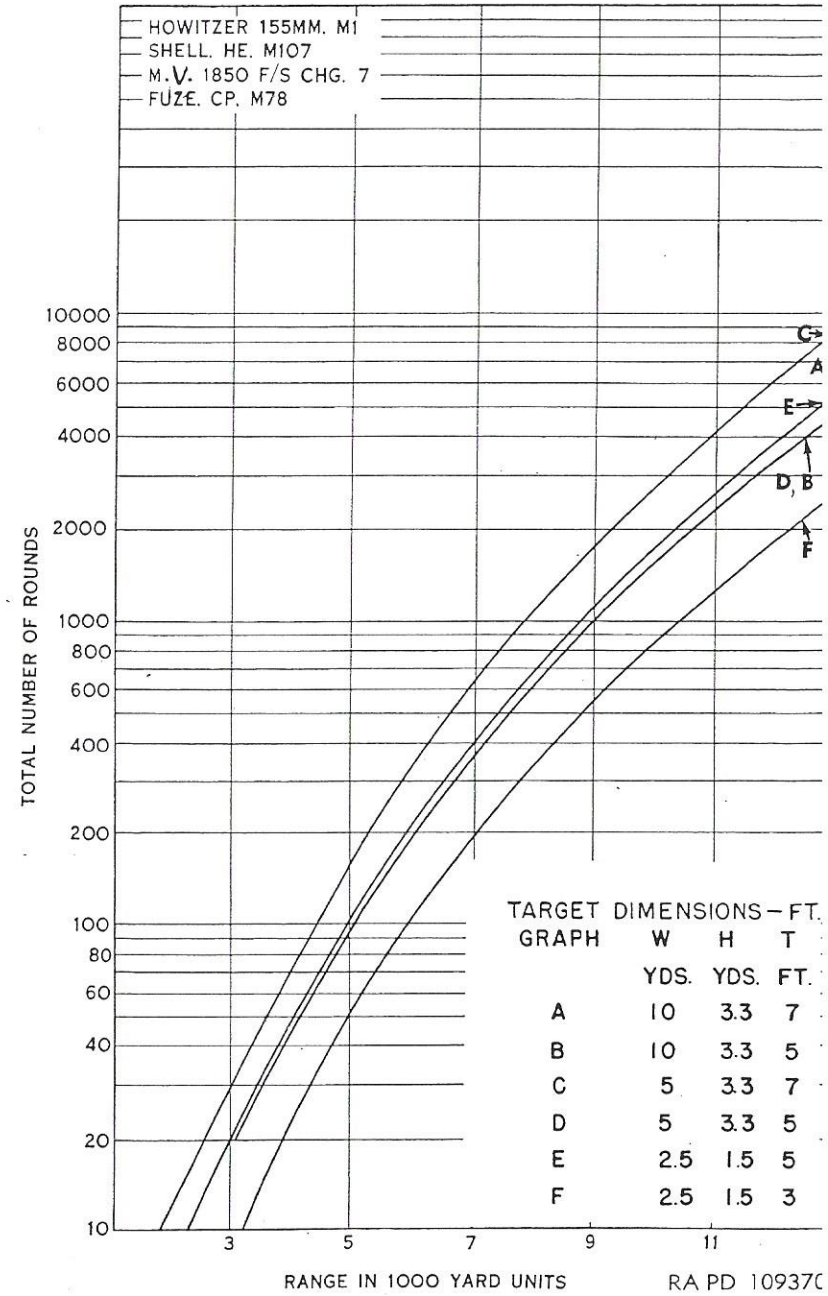


Figure 128. Number of rounds required for single perforation of concrete wa (compressive strength 5,000 psi) (90 percent probability of one or more perforations (155H: HE w/CPF (MV 1850)).

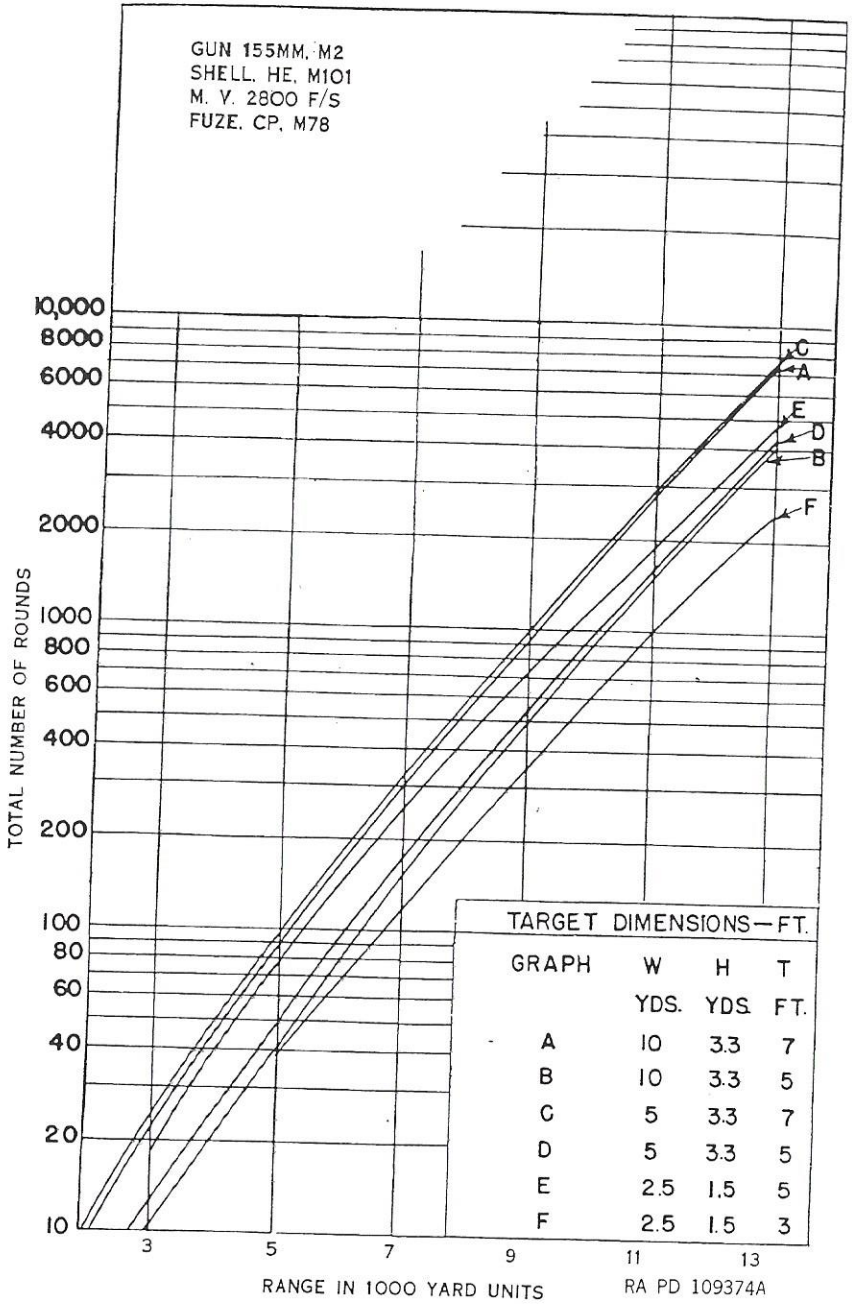


Figure 129. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (155G: HE w/CPF (MV 2800)).

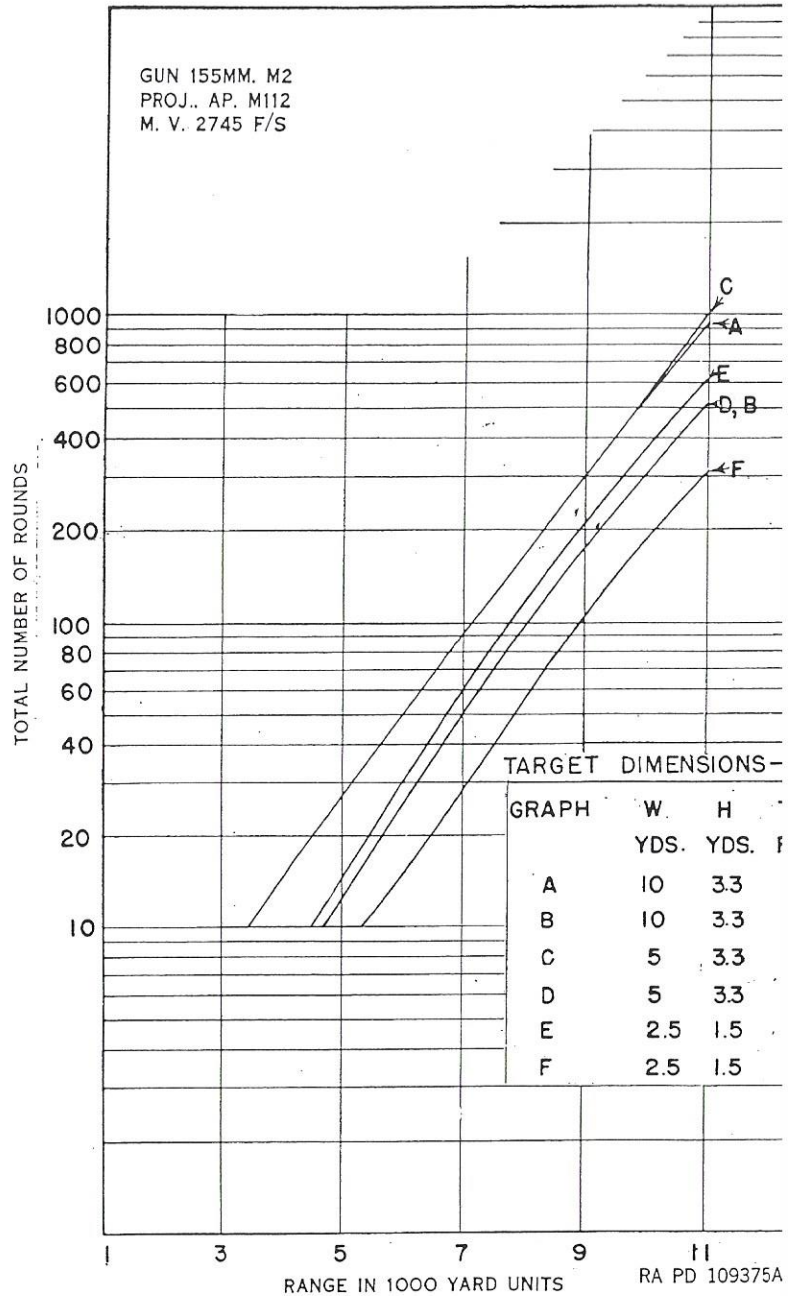


Figure 130. Number of rounds required for single perforation of concrete (compressive strength 5,000 psi) (90 percent probability of one or more perforati (155G: AP (MV 2745)).

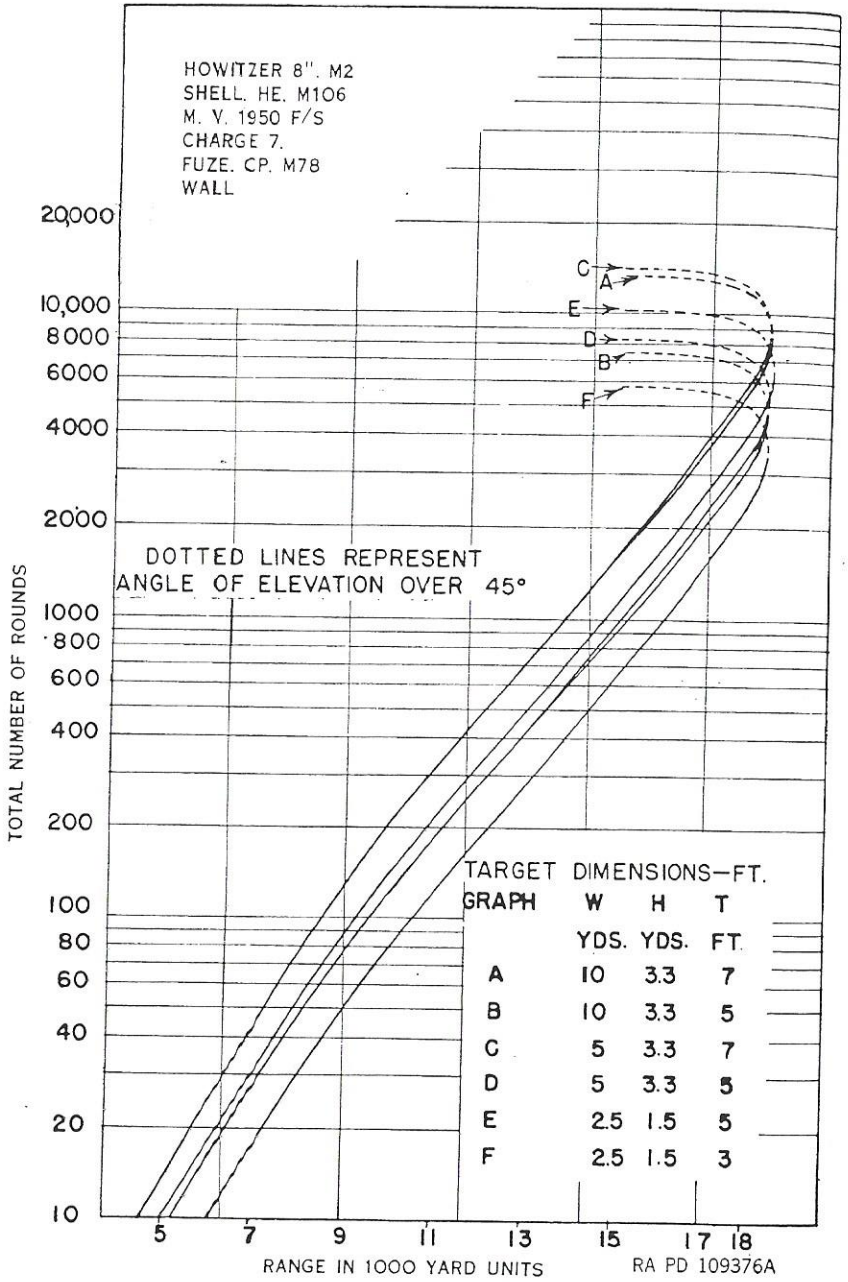


Figure 131. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (8H: HE w/CPF; Chg 7 (MV 1950)).

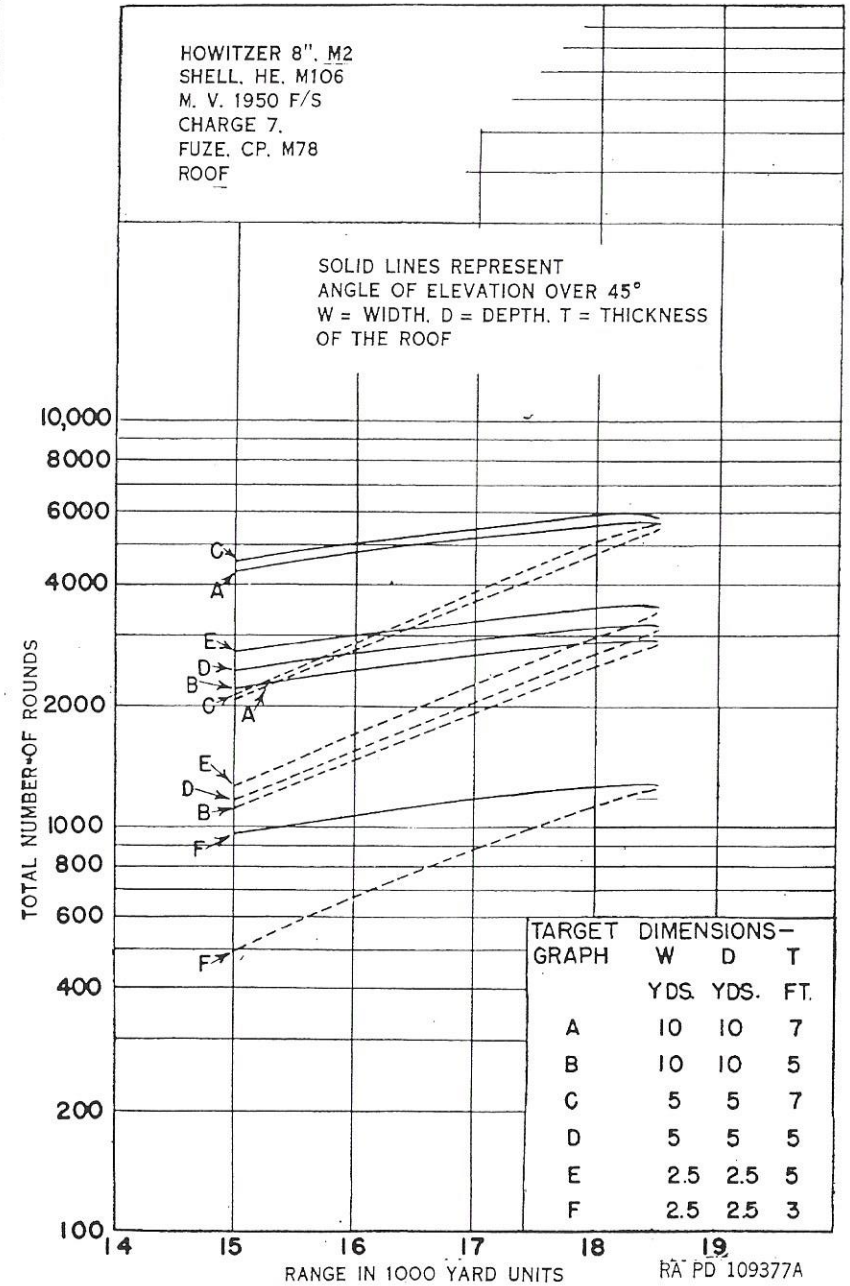


Figure 132. Number of rounds required for single penetration of concrete roof (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (8H: HE w/CPF: Chg 7 (MV 1950)).

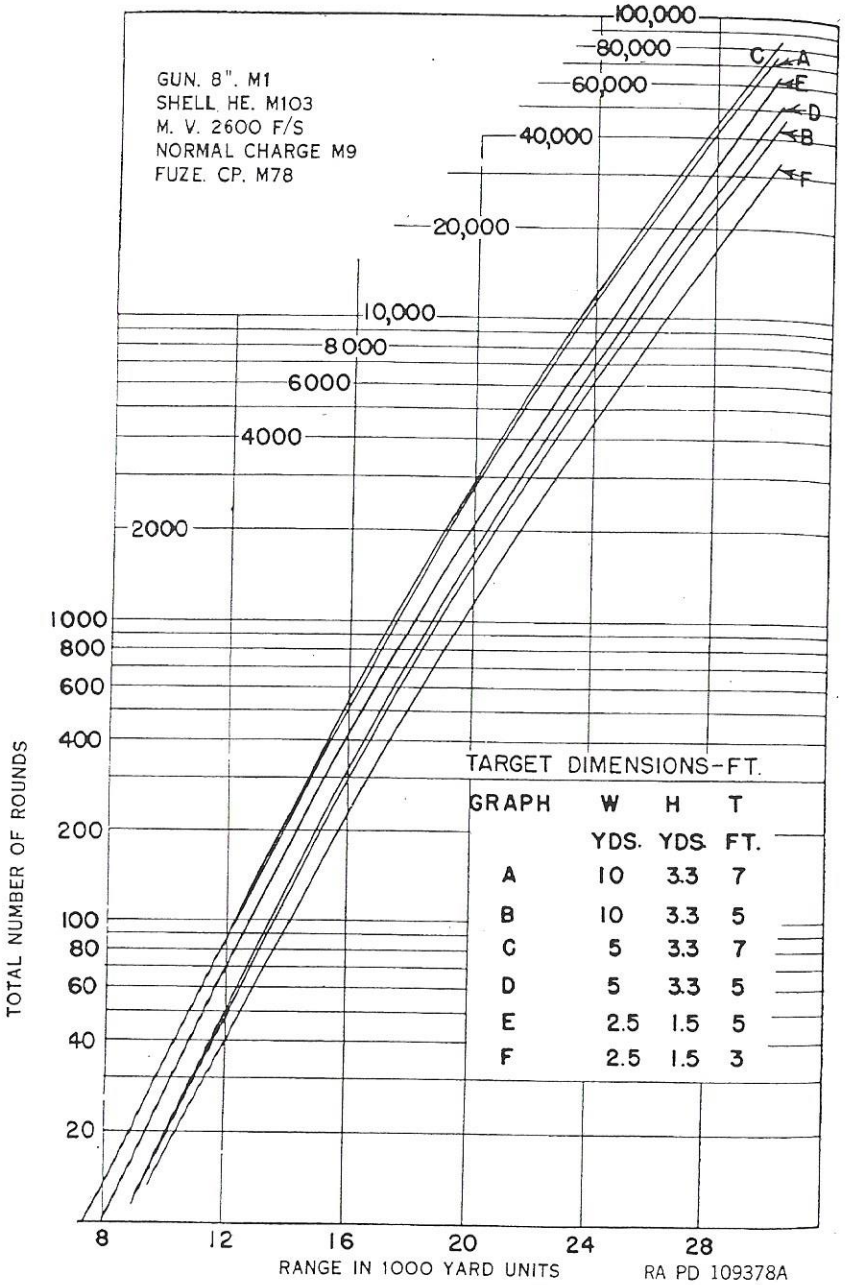


Figure 133. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (8G: HE w/CPF: NC (MV 2600)).

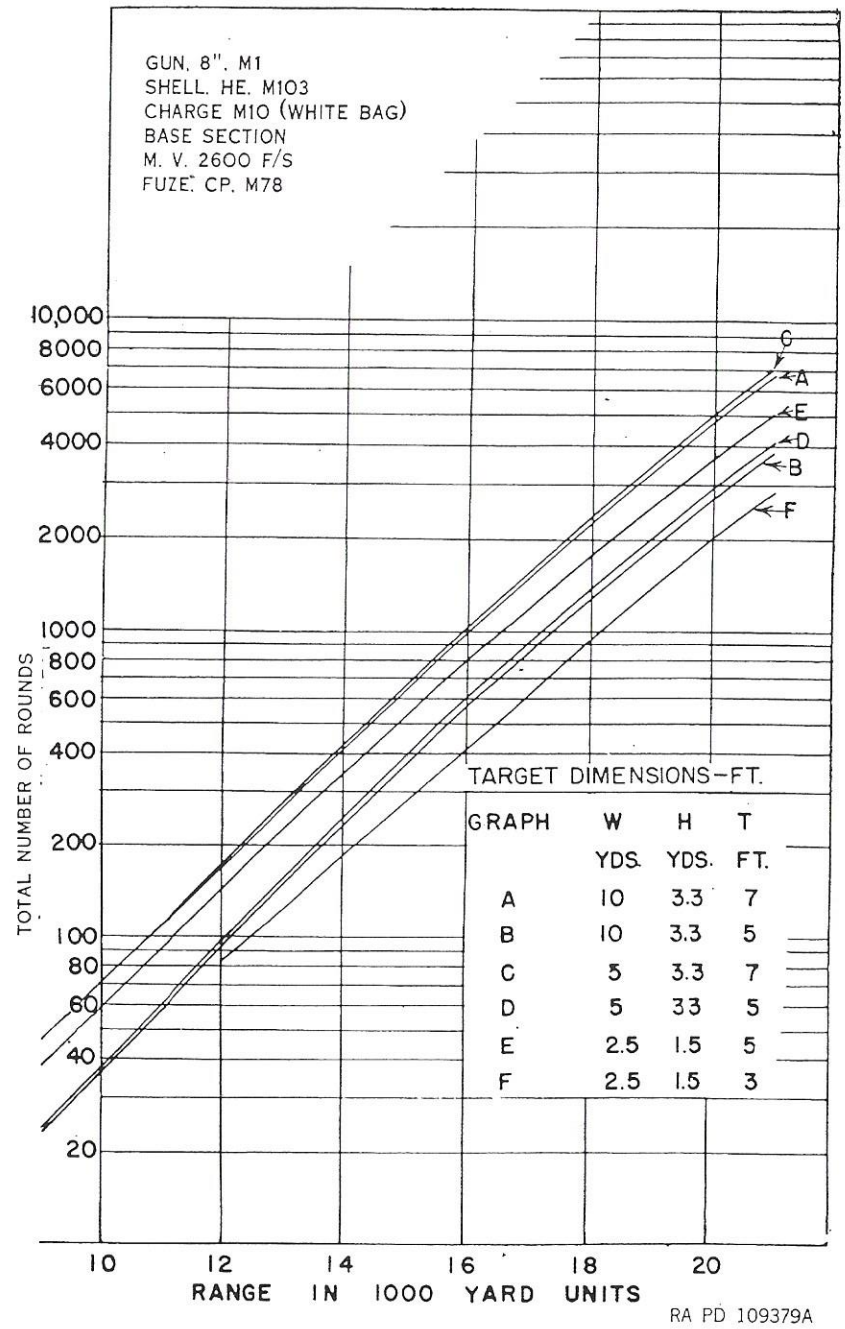


Figure 134. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (8G: HE w/CPF: Chg M10 base (MV 2600)).

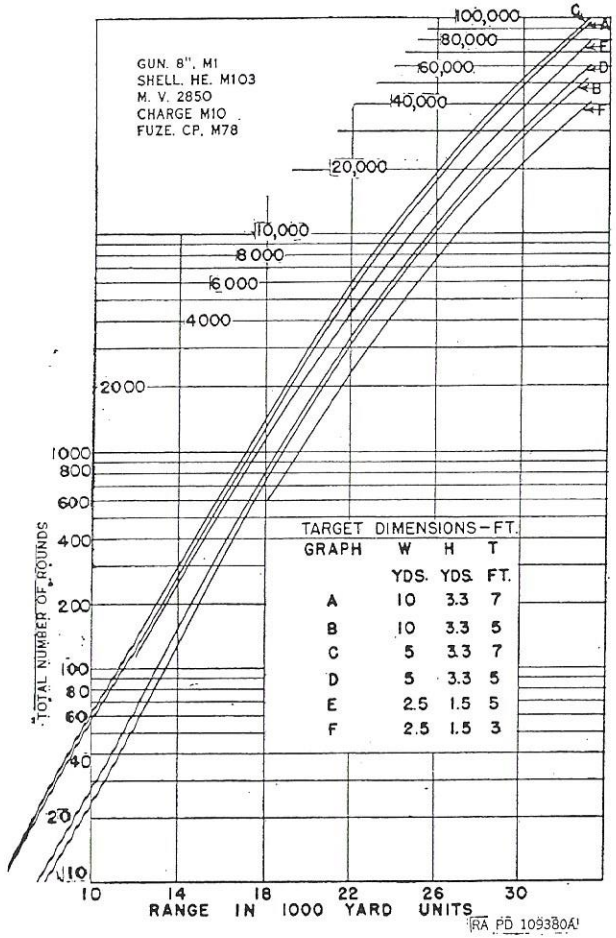


Figure 135. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (8G: HE w/CPF: Chg M10 (MV 2850)).

(*b*) Complete round weight.

(*c*) Muzzle velocity.

(*d*) Range and corresponding terminal velocity, penetration depth, and perforation thickness.

(*e*) For a 10-foot high by 6-foot thick wall, and for a 10-foot high by 10-foot thick wall, the following data for making a breach 4 yards wide in grade A concrete having a compressive strength of 5,000 pounds per square inch: Necessary number of hits; total number of rounds; total complete round weight; number of rounds fired at each point of aim; deflection difference between successive aiming points in feet; and number of different aiming points.

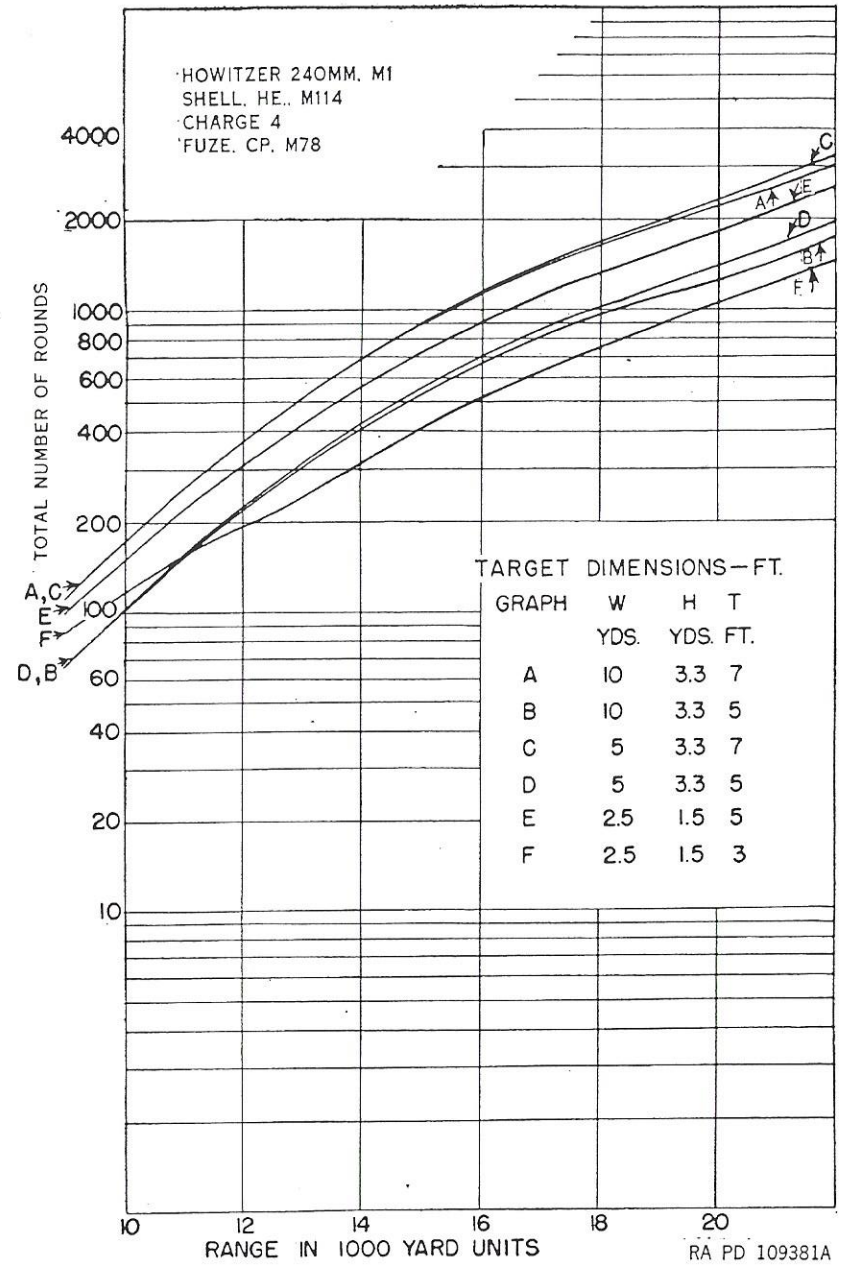


Figure 136. Number of rounds required for single perforation of concrete wall (compressive strength 5,000 psi) (90 percent probability of one or more perforations) (240H: HE w/CPF: Chg 4 (MV 2300)).

Table LII. Total Number and Weight of Rounds Required for at Least One Perforation of Pillbox Wall
(Compressive strength 5,000 psi) (90 percent probability)

Weapon	Ammunition	MV f/s	Range (yd)	Rounds required for at least one perforation of pillbox wall					
				3 feet thick 7½ feet wide 4½ feet high		5 feet thick = or >15 feet wide = or >10 feet high		7 feet thick = or >15 feet wide = or >10 feet high	
				No.	Weight	No.	Weight	No.	Weight
Gun, 75-mm, M3, M6, M17	Projectile, fixed, APC-T, M61	2,030	1,000	10	200	20	400	35	720
			2,000	50	1,000	110	2,200	180	3,600
			3,000	200	4,000	480	9,600	750	15,000
			4,000	730	14,700	1,700	34,000	—	—
	Shell, fixed, HE, M48 supercharge w/fuze CP, M78	1,980	1,000	10	202	20	400	40	810
			2,000	50	1,000	115	2,300	200	4,000
			3,000	220	4,400	500	10,000	900	18,000
			4,000	750	15,000	1,800	36,500	—	—
	Shell, fixed, HE, M48, normal charge, w/fuze CP, M78	1,520	500	7	136	15	290	35	680
			1,000	20	390	45	880	80	1,600
			2,000	100	1,950	240	4,700	430	8,300
			3,000	370	7,200	880	17,000	1,500	29,000
Gun, 76-mm, M1A1C, M1A2	Shell, fixed, HE, M42A1, w/fuze CP, M78	2,700	1,000	6	140	15	340	20	460
			2,000	30	700	55	1,200	90	2,000
			3,000	115	2,600	240	5,500	430	9,800
			4,000	430	9,800	900	20,000	—	—
			5,000	1,400	32,000	—	—	—	—
Gun, 90-mm, M1, M1A1, M2, M3	Projectile, fixed, APC-T, M82	2,670	1,000	3	130	6	250	8	340
			2,000	8	340	15	640	25	1,100
			3,000	25	1,080	50	2,100	85	3,700
			4,000	70	3,000	130	5,500	230	9,800
			5,000	160	6,900	320	14,000	580	25,000
	Shell, fixed, HE, M71, w/fuze CP, M78	2,700	1,000	3	135	5	200	9	380
			2,000	9	400	15	640	30	1,100
			3,000	27	1,200	50	2,200	90	3,800
			4,000	65	2,700	140	6,000	250	11,000
			5,000	175	7,500	350	15,000	600	26,000
Howitzer, 105-mm, M2A1, M4	Shell, semifixed, HE, M1, w/fuze CP, M78: 105-mm how, M2A1, M4, charge 7	1,550	1,000	8	340	15	640	30	1,100
			2,000	35	1,500	70	3,000	130	5,500
			3,000	120	5,200	270	12,000	480	20,000
			4,000	350	15,000	750	32,000	1,400	60,000
			5,000	710	30,000	—	—	—	—
Howitzer, 105-mm, M3, M2A1, M4	Shell, semifixed, HE, M1, w/fuze, CP, M78: 105-mm how, M3, charge 5	1,020	1,000	8	340	200	8,300	350	15,000
Howitzer, 155-mm, M1	Shell, HE, M107, w/fuze, CP, M78, charge 7	1,850	1,000	2	220	4	430	5	540
			2,000	4	440	10	1,100	15	1,600
			3,000	9	1,000	20	2,200	30	3,300
			4,000	23	2,500	45	4,900	70	7,600
			5,000	52	5,700	100	10,900	160	17,000
			6,000	105	11,400	200	22,000	330	36,000
			8,000	330	36,000	600	65,000	1,000	110,000

Table LII. Total Number and Weight of Rounds Required for at Least One Perforation of Pillbox Wall—Continued
(Compressive strength 5,000 psi) (90 percent probability)

Weapon	Ammunition	MV f/s	Range (yd)	Rounds required for at least one perforation of pillbox wall: 3 feet thick, 7½ feet wide, 4½ feet high		5 feet thick, = or >15 feet wide, = or >10 feet high		7 feet thick, = or >15 feet wide, = or >10 feet high	
				No.	Weight	No.	Weight	No.	Weight
Gun, 155-mm, M2	Shell, HE, M101, w/fuze, CP, M78, supercharge	2,800	1,000	3	380	—	—	4	500
			2,000	6	760	5	630	(4)* 10	(500)* 1,250
			3,000	12	1,500	10	1,300	(10)* 25	(1,250)* 3,100
			4,000	20	2,500	(15)* 20	(1,900)* 2,500	(20)* 50	(2,500)* 6,400
			5,000	38	4,800	(25)* 40	(3,200)* 5,000	(45)* 95	(5,700)* 12,000
			6,000	65	8,200	(50)* 80	(6,300)* 10,000	(85)* 180	(11,000)* 23,000
			8,000	200	25,000	(90)* 300	(11,000)* 38,000	(160)* 510	(20,000)* 67,000
			10,000	600	76,000	(300)* 900	(38,000)* 108,000	(520)* 1,800	(64,000)* 230,000
								(1,600)*	(200,000)*
	Projectile, AP, M112	2,745	1,000	3	400	—	—	5	660
			2,000	3	400	—	—	6	790
			3,000	4	530	4	520	8	1,060
			4,000	6	790	7	900	15	2,000
			5,000	9	1,200	15	2,000	25	3,300
			6,000	15	2,000	30	4,000	50	6,600
			8,000	55	7,200	100	13,000	170	22,000
			10,000	190	25,000	300	39,000	550	73,000
			12,000	—	—	800	100,000	—	—
Howitzer, 8-inch, M2	Shell, HE, M106, w/fuze, CP, M78, charge 7	1,950	5,000	6	1,300	10	2,300	15	3,400
			6,000	10	2,300	15	3,400	25	5,700
			8,000	30	6,900	45	10,000	75	17,000
			10,000	80	18,000	110	26,000	200	46,000
			12,000	190	44,000	300	69,000	450	100,000
			14,000	460	105,000	600	140,000	1,000	230,000
Gun, 8-inch, M1	Shell, HE, M103, w/fuze, CP, M78, supercharge	2,850	6,000	15	5,000	—	—	10	3,500
			8,000	25	8,500	10	3,500	30	10,000
			10,000	45	15,000	25	8,500	60	21,000
			12,000	85	29,000	50	17,000	130	44,000
			14,000	155	53,000	150	50,000	300	100,000
			16,000	290	99,000	—	—	650	220,000
	Shell, HE, M103, w/fuze, CP, M78, normal charge —M10-base	2,600	6,000	10	3,400	—	—	—	—
			8,000	20	6,800	15	5,000	40	14,000
			10,000	40	14,000	35	12,000	70	24,000
			12,000	85	29,000	100	34,000	180	62,000
			14,000	185	63,000	220	75,000	—	—
			16,000	410	140,000	—	—	—	—
	Shell, HE, M103, w/fuze, CP, M78, normal charge —M9 full charge	2,600	6,000	5	1,700	—	—	—	—
			8,000	9	3,000	—	—	15	5,000
			10,000	17	5,800	20	6,800	35	12,000
			12,000	40	14,000	50	17,000	85	29,000
			14,000	90	31,000	140	48,000	220	75,000
			16,000	220	75,000	—	—	520	180,000

* Figures in parentheses relate to target 10 feet high by 30 feet wide.

Table LII. Total Number and Weight of Rounds Required for at Least One Perforation of Pillbox Wall—Continued
(Compressive strength 5,000 psi) (90 percent probability)

Weapon	Ammunition	MV f/s	Range (yd)	Rounds required for at least one perforation of pillbox wall					
				3 feet thick 7½ feet wide 4½ feet high		5 feet thick = or >15 feet wide = or >10 feet high		7 feet thick = or >15 feet wide = or >10 feet high	
				No.	Weight	No.	Weight	No.	Weight
Howitzer, 240-mm, M1	Shell, HE, M114, w/fuze, CP, M78, charge 4	2,300	8,000	60	26,500	40	18,000	70	31,000
			10,000	120	53,000	100	44,000	170	75,000
			12,000	200	80,000	230	100,000	370	160,000
			14,000	320	140,000	430	190,000	700	300,000
			16,000	530	230,000	—	—	—	—

Table LIII. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 57-mm Gun M1 Firing APC-T Projectile M86

Projectile weight: 7.27 lb. Complete round weight: 13.73 lb. Muzzle velocity: 2,700 f/s

Range (yd.)			0	500	1,000	2,000	3,000
Terminal velocity (f/s)			2,700	2,510	2,320	1,950	1,620
Probability of hitting target 1 yd. square in any one round				.08			
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	2.3	2.0	1.8	1.4	1.2
		Face vertical (ft.)	2.3	2.0	1.8	1.4	1.2
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	3.2	2.7	2.6	2.1	1.7
		Face vertical (ft.)	3.2	2.7	2.6	2.1	1.7
	Volume of concrete excavated by first round (cu. ft.)			3			
	Number of rounds falling in circle of —— yd. diameter necessary to perforate concrete	3 ft. thick					
		5 ft. thick					
		7 ft. thick					
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep						
	Necessary number of hits			175			
	Total number of rounds			370			
	Total complete round weight (lb.)			5,100			
	No. of rds. fired at each point of aim			370			
	Deflection difference between successive aiming points (ft.)						
	No. of different aiming points			1			
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep						
	Necessary number of hits			300			
	Total number of rounds			620			
	Total complete round weight (lb.)			8,500			
	No. of rds. fired at each point of aim			620			
	Deflection difference between successive aiming point (ft.)						
	No. of different aiming points			1			

Table LIV. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 75-mm Gun M3, M6, M17 Firing HE Shell M48 with CP Fuze 78

Shell weight: 15.04 lb. Complete round weight: 19.93 lb. Muzzle velocity: 1,980 f/s

Range (yd.)			0	500	1,000	2,000	3,000	4,000	5,000
Terminal velocity (f/s)			1,980	1,850	1,720	1,490	1,290	1,130	1,020
Probability of hitting target 1 yd. square in any one round					0.85	0.19	0.057	0.022	0.010
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	1.7	1.6	1.6	1.3	0.9	0.8	0.7
		Face vertical (ft.)	1.7	1.7	1.6	1.3	0.9	0.8	0.6
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	2.4	2.1	1.9	1.7	1.5	1.3	1.2
		Face vertical (ft.)	2.4	2.1	1.9	1.7	1.5	1.3	1.2
	Volume of concrete excavated by first round (cu. ft.)				3	3			
	Number of rounds falling in circle of 0.83 yd. diameter necessary to perforate concrete	3 ft. thick			5	8	13	17	20
		5 ft. thick			14	21	36	48	63
		7 ft. thick			27	41	72		
Breaching	Concrete wall 10 ft high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep								
	Necessary number of hits				200	240			
	Total number of rounds				210	260			
	Total complete round weight (lb.)				4,200	5,200			
	No. of rds. fired at each point of aim				35	65			
	Deflection difference between successive aiming points (ft.)				2	3			
	No. of different aiming points				6	4			
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep								
	Necessary number of hits				320	400			
	Total number of rounds				360	420			
	Total complete round weight (lb.)				7,200	8,400			
	No. of rds. fired at each point of aim				60	105			
	Deflection difference between successive aiming points (ft.)				2	3			
	No. of different aiming points				6	4			

Table LV. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 75-mm Gun M3, M6, M17 Firing APC-T Projectile M61 or M61A1

Projectile weight: 14.90 lb. Complete round weight: 20.08 lb. Muzzle velocity: 2,030 f/s

Range (yd.)			0	500	1,000	2,000	3,000	4,000	5,000
Terminal velocity (f/s)			2,030	1,900	1,770	1,520	1,300	1,120	1,020
Probability of hitting target 1 yd. square in any one round					0.85	0.19	0.057	0.022	0.0096
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	1.9	1.7	1.6	1.3	1.0	0.8	0.7
		Face vertical (ft.)	1.9	1.7	1.6	1.3	1.0	0.8	0.7
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	2.5	2.3	2.1	1.8	1.5	1.3	1.2
		Face vertical (ft.)	2.5	2.3	2.1	1.8	1.5	1.3	1.2
	Volume of concrete excavated by first round (cu. ft.)				3	3			
	Number of rounds falling in circle of 0.83 yd. diameter necessary to perforate concrete	3 ft. thick			5	7	10	17	21
		5 ft. thick			13	19	30	47	
		7 ft. thick			25	27	60		
Breaching*	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep								
	Necessary number of hits				200	240			
	Total number of rounds				210	260			
	Total complete round weight (lb.)				4,200	5,200			
	No. of rds. fired at each point of aim				35	65			
	Deflection difference between successive aiming points (ft.)				2	3			
	No. of different aiming points				6	4			
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep								
	Necessary number of hits				320	400			
	Total number of rounds				360	420			
	Total complete round weight (lb.)				7,200	8,400			
	No. of rds. fired at each point of aim				60	105			
	Deflection difference between successive aiming points (ft.)				2	3			
	No. of different aiming points				6	4			

* Replace about one-fifth of rounds with HE shell, superquick fuzed, against reinforced concrete.

Table LVI. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 76-mm Gun M1A1C, M1A2 Firing HE Shell M42A1 with CP Fuze M78

Projectile weight: 13.21 lb. Complete round weight: 22.39 lb. Muzzle velocity: 2,700 f/s

Range (yd.)			0	500	1,000	2,000	3,000	4,000	5,000
Terminal velocity (f/s)			2,700	2,520	2,345	2,007	1,695	1,411	1,169
Probability of hitting target 1 yd. square in any one round					0.85	0.19	0.056	0.023	0.010
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	2.6	2.3	2.0	1.7	1.4	1.0	0.8
		Face vertical (ft.)	2.6	2.3	2.0	1.7	1.4	1.0	0.8
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	3.6	3.2	3.0	2.5	2.1	1.6	1.4
		Face vertical (ft.)	3.6	3.2	3.0	2.5	2.1	1.6	1.4
	Volume of concrete excavated by first round (cu. ft.)				6				
	Number of rounds falling in circle of 0.83 yd. diameter necessary to perforate concrete	3 ft. thick			1	3	5	10	15
		5 ft. thick			5	8	14	30	43
		7 ft. thick			10	16	27		
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep								
	Necessary number of hits				100				
	Total number of rounds				210				
	Total complete round weight (lb.)				4,700				
	No. of rds. fired at each point of aim				35				
	Deflection difference between successive aiming points (ft.)				2				
	No. of different aiming points				6				
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep								
	Necessary number of hits				170				
	Total number of rounds				360				
	Total complete round weight (lb.)				8,100				
	No. of rds. fired at each point of aim				60				
	Deflection difference between successive aiming points (ft.)				2				
	No. of different aiming points				6				

Table LVII. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 76-mm Gun M1A1C, M1A2 Firing APC-T Projectile M62 or M62A1

Projectile weight: 15.40 lb. Complete round weight: 24.67 lb. Muzzle velocity: 2,600 f/s

Range (yd.)			0	500	1,000	2,000	3,000	4,000	5,000
Terminal velocity (f/s)			2,600	2,450	2,290	2,000	1,720	1,466	1,240
Probability of hitting target 1 yd. square in any one round					0.49	0.10	0.034	0.015	0.0063
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	2.6	2.5	2.3	1.9	1.5	1.2	1.0
		Face vertical (ft.)	2.6	2.5	2.3	1.9	1.5	1.2	0.9
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	3.6	3.3	3.1	2.6	2.2	1.8	1.5
		Face vertical (ft.)	3.6	3.3	3.1	2.6	2.2	1.8	1.5
	Volume of concrete excavated by first round (cu. ft.)				6				
	Number of rounds falling in circle of 0.83 yd. diameter necessary to perforate concrete	3 ft. thick			1	3	5	8	12
		5 ft. thick			6	9	14	21	35
		7 ft. thick			12	18	26	40	
Breaching*	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep								
	Necessary number of hits				110				
	Total number of rounds				210				
	Total complete round weight (lb.)				5,200				
	No. of rds. fired at each point of aim				35				
	Deflection difference between successive aiming points (ft.)				2				
	No. of different aiming points				6				
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep								
	Necessary number of hits				180				
	Total number of rounds				360				
	Total complete round weight (lb.)				8,900				
	No. of rds. fired at each point of aim				60				
	Deflection difference between successive aiming points (ft.)				2				
	No. of different aiming points				6				

* Replace about one-fifth of rounds with HE shell, superquick fuzed, against reinforced concrete.

Table LVIII. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 90-mm Gun M1, M1A1, M2 or M3 Firing HE Shell M71 with CP Fuze M78

Projectile weight: 23.74 lb. Complete round weight: 42.38 lb. Muzzle velocity: 2,700 f/s

Range (yd.)			0	1,000	2,000	3,000	4,000	6,000	8,000
Terminal velocity (f/s)			2,700	2,460	2,230	2,010	1,800	1,400	1,100
Probability of hitting target 1 yd. square in any one round							0.047		
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	3.0	2.7	2.4	2.0	1.7	1.1	0.8
		Face vertical (ft.)	3.0	2.7	2.4	2.0	1.7	1.1	0.7
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	4.2	3.8	3.4	3.0	2.6	1.9	1.6
		Face vertical (ft.)	4.2	3.8	3.4	3.0	2.6	1.9	1.6
	Volume of concrete excavated by first round (cu. ft.)			11	9	8	7	6	
	Number of rounds falling in circle of 1 yd. diameter necessary to perforate concrete	3 ft. thick		1	1	3	3		
		5 ft. thick		3	5	8	10		
		7 ft. thick		7	10	14	20		
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep								
	Necessary number of hits			60	75	90	115		
	Total number of rounds			72	130	240	520		
	Total complete round weight (lb.)			3,100	5,500	10,200	22,000		
	No. of rds. fired at each point of aim			12	65	120	260		
	Deflection difference between successive aiming points (ft.)			2	6	6	6		
	No. of different aiming points			6	2	2	2		
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep								
	Necessary number of hits			100	120	150	185		
	Total number of rounds			132	180	380	840		
	Total complete round weight (lb.)			5,600	7,700	16,200	35,900		
	No. of rds. fired at each point of aim			22	90	190	420		
	Deflection difference between successive aiming points (ft.)			2	6	6	6		
	No. of different aiming points			6	2	2	2		

Table LIX. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 90-mm Gun M1, M1A1, M2 or M3 Firing APC-T Projectile M82

Projectile weight: 24.10 lb. Complete round weight: 42.75 lb. Muzzle velocity: 2,670 f/s

Range (yd.)			0	1,000	2,000	3,000	4,000	6,000	8,000
Terminal velocity (f/s)			2,670	2,440	2,200	2,015	1,770	1,380	1,100
Probability of hitting target 1 yd. square in any one round					0.36		0.052	0.013	
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	3.0	2.7	2.2	1.8	1.6	1.2	0.8
		Face vertical (ft.)	3.0	2.7	2.2	1.8	1.6	1.1	0.7
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	4.2	3.7	3.2	2.7	2.4	1.9	1.4
		Face vertical (ft.)	4.2	3.7	3.2	2.7	2.4	1.9	1.4
	Volume of concrete excavated by first round (cu. ft.)			11	9	8	7	6	
	Number of rounds falling in circle of 1 yd. diameter necessary to perforate concrete	3 ft. thick		1	1	3	4	6	
		5 ft. thick		3	5	7	9		
		7 ft. thick		7	10	14	18		
Breaching*	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep								
	Necessary number of hits			60	75	90	115		
	Total number of rounds			72	130	240	520		
	Total complete round weight (lb.)			3,100	5,600	10,300	22,200		
	No. of rds. fired at each point of aim			12	65	120	260		
	Deflection difference between successive aiming points (ft.)			2	6	6	6		
	No. of different aiming points			6	2	2	2		
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep								
	Necessary number of hits			100	125	150	190		
	Total number of rounds			132	180	380	840		
	Total complete round weight (lb.)			5,600	7,700	16,200	35,900		
	No. of rds. fired at each point of aim			22	90	190	420		
	Deflection difference between successive aiming points (ft.)			2	6	6	6		
	No. of different aiming points			6	2	2	2		

* Replace about one-fifth of rounds with HE shell, superquick fuzed, against reinforced concrete.

Table LX. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 105-mm Howitzer M2A1 or M4 Firing HE Shell M1 with CP Fuze M78

Projectile weight: 33.82 lb. Complete round weight: 42.89 lb. Muzzle velocity: 1,550 f/s

Range (yd.)			0	500	1,000	2,000	3,000	4,000	5,000	8,000
Terminal velocity (f/s)			1,550	1,460	1,370	1,210	1,080	1,020	980	900
Probability of hitting target 1 yd. square in any one round							0.065		0.012	
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	1.5	1.4	1.3	1.1	0.9	0.8	0.9	
		Face vertical (ft.)	1.5	1.3	1.2	1.0	0.9	0.8	0.7	
		Face horizontal* (ft.)							0.5	0.6
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	2.4	2.3	2.1	1.8	1.6	1.5	1.5	
		Face vertical (ft.)	2.4	2.3	2.1	1.8	1.6	1.5	1.4	
		Face horizontal* (ft.)							1.1	1.1
	Volume of concrete excavated by first round (cu. ft.)				7	6	5			
	Number of rounds falling in circle of 1 yd. diameter necessary to perforate concrete	3 ft. thick			5		10		12	
		5 ft. thick			14		27		33	
		7 ft. thick			27		53		64	
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep									
	Necessary number of hits				90	110	120			
	Total number of rounds				120	220	540			
	Total complete round weight (lb.)				5,100	9,400	23,200			
	No. of rds. fired at each point of aim				20	110	270			
	Deflection difference between successive aiming points (ft.)				2	6	6			
	No. of different aiming points				6	2	2			
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep									
	Necessary number of hits				150	175	200			
	Total number of rounds				180	360	880			
	Total complete round weight (lb.)				7,700	15,400	37,700			
	No. of rds. fired at each point of aim				30	180	440			
	Deflection difference between successive aiming points (ft.)				2	6	6			
	No. of different aiming points				6	2	2			

* High-angle fire to be used against horizontal targets. Zone 6 charge for 8,000-yd. range; zone 4, for 5,000-yd. range.

Table LXI. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 105-mm Howitzer M3 Firing HE Shell M1 with CP Fuze M78

Projectile weight: 33.82 lb. Complete round weight: 41.18 lb. Muzzle velocity: 1,020 f/s

Range (yd.)			0	500	1,000	2,000	3,000	4,000	5,000
Terminal velocity (f/s)			1,020	990	970	930	890	860	830
Probability of hitting target 1 yd. square in any one round					0.11				
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	1.0	0.9	0.8	0.7	0.7	0.7	0.7
		Face vertical (ft.)	1.0	0.9	0.8	0.7	0.6	0.5	0.5
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	1.6	1.5	1.4	1.4	1.4	1.3	1.3
		Face vertical (ft.)	1.6	1.5	1.4	1.3	1.3	1.2	1.2
	Volume of concrete excavated by first round (cu. ft.)				3	3			
	Number of rounds falling in circle of 1 yd. diameter necessary to perforate concrete	3 ft. thick			12				
		5 ft. thick			33				
		7 ft. thick			65				
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep								
	Necessary number of hits				240				
	Total number of rounds				510				
	Total complete round weight (lb.)				21,000				
	No. of rds. fired at each point of aim				170				
	Deflection difference between successive aiming points (ft.)				4				
	No. of different aiming points				3				
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep								
	Necessary number of hits				400				
	Total number of rounds				720				
	Total complete round weight (lb.)				29,600				
	No. of rds. fired at each point of aim				240				
	Deflection difference between successive aiming points (ft.)				4				
	No. of different aiming points				3				

Table LXII. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 155-mm Howitzer M1 Firing HE Shell M107 with CP Fuze M78

Projectile weight: 95.35 lb. Complete round weight: 108.48 lb. Muzzle velocity: 1,850 f/s

Range (yd.)			0	1,000	3,000	5,000	7,500	10,000	12,500	15,000
Terminal velocity (f/s)			1,850	1,710	1,570	1,210	1,030	990	980	1,010
Probability of hitting target 1 yd. square in any one round					0.19	0.044	0.014	0.0035	0.0015	0.0004
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	2.9	2.6	2.0	1.6	1.3	1.2	1.2	1.3
		Face vertical (ft.)	2.9	2.6	2.0	1.5	1.1	0.9	0.7	
		Face horizontal*						0.9	1.1	
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	4.2	3.9	3.2	2.7	2.4	2.2	2.2	2.3
		Face vertical (ft.)	4.2	3.9	3.2	2.6	2.2	1.8		
		Face horizontal*						1.9	2.2	
	Volume of concrete excavated by first round (cu. ft.)			22	16	11				
	Number of rounds falling in circle of 1.33 yd. diameter necessary to perforate concrete	3 ft. thick		1	1	2	5	5	5	5
		5 ft. thick		3	5	9	13	14	14	13
		7 ft. thick		7	11	18	25	28	28	25
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep									
	Necessary number of hits			30	40	60				
	Total number of rounds			36	100	420				
	Total complete round weight (lb.)			3,900	10,800	45,600				
	No. of rds. fired at each point of aim			6	50	210				
	Deflection difference between successive aiming points (ft.)			2	6	6				
	No. of different aiming points			6	2	2				
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep									
	Necessary number of hits			50	70	95				
	Total number of rounds			60	160	620				
	Total complete round weight (lb.)			6,500	17,400	67,300				
	No. of rds. fired at each point of aim			10	80	310				
	Deflection difference between successive aiming points (ft.)			2	6	6				
	No. of different aiming points			6	2	2				

* High angle fire to be used against horizontal targets. Zone 6 charge for 12,500-yd. range; zone 5 for 10,000-yd. range.

Table LXIII. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 155-mm Gun M2 Firing HE Shell M101 with CP Fuze M78

Projectile weight: 95.14 lb. Complete round weight: 125.82 lb. Muzzle velocity: 2,800 f/s

Range (yd.)			0	1,000	3,000	5,000	7,500	10,000	12,500	15,000
Terminal velocity (f/s)			2,800	2,640	2,330	2,030	1,680	1,370	1,130	1,050
Probability of hitting target 1 yd. square in any one round					0.075	0.021	0.0065	0.0026	0.0012	
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	5.0	4.6	4.0	3.2	2.4	1.9	1.4	1.2
		Face vertical (ft.)	5.0	4.6	4.0	3.2	2.3	1.7	1.2	0.9
		Face horizontal* (ft.)								1.1
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	7.0	6.6	5.6	4.6	3.6	3.0	2.6	2.3
		Face vertical (ft.)	7.0	6.6	5.6	4.6	3.5	2.9	2.3	1.9
		Face horizontal* (ft.)								2.2
	Volume of concrete excavated by first round (cu. ft.)			51	40	30				
	Number of rounds falling in circle of 1.33 yd. diameter necessary to perforate concrete	3 ft. thick		1	1	1	1	1–2	3	
		5 ft. thick		1	1	2	3	5	9	
		7 ft. thick		2	3	4	6	10	17	
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep									
	Necessary number of hits			12	16	21				
	Total number of rounds			16	70	240				
	Total complete round weight (lb.)			2,000	8,900	30,200				
	No. of rds. fired at each point of aim			8						
	Deflection difference between successive aiming points (ft.)			6						
	No. of different aiming points			2	1	1				
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep									
	Necessary number of hits			21	27	35				
	Total number of rounds			28	110	380				
	Total complete round weight (lb.)			3,500	13,800	47,800				
	No. of rds. fired at each point of aim			14						
	Deflection difference between successive aiming points (ft.)			6						
	No. of different aiming points			2	1	1				

Table LXIV. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 155-mm Gun M2 Firing AP Projectile M112

Projectile weight: 100.00 lb. Complete round weight: 131.28 lb. Muzzle velocity: 2,745 f/s

Range (yd.)			0	1,000	3,000	5,000	7,500	10,000	12,500	15,000
Terminal velocity (f/s)			2,745	2,580	2,260	1,940	1,570	1,270	1,080	1,010
Probability of hitting target 1 yd. square in any one round					0.5	0.10	0.028	0.0095	0.0045	
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	5.2	4.8	4.0	3.2	2.4	1.8	1.4	1.3
		Face vertical (ft.)	5.2	4.8	4.0	3.1	2.2	1.6	1.1	0.8
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	7.1	6.5	5.4	4.5	3.6	2.9	2.4	2.3
		Face vertical (ft.)	7.1	6.5	5.4	4.5	3.5	2.7	2.2	1.8
	Volume of concrete excavated by first round (cu. ft.)			51	45	29	20			
	Number of rounds falling in circle of 1.33 yd. diameter necessary to perforate concrete	3 ft. thick		1	1	1	1	1–2	4	
		5 ft. thick		1	1	3	4	7	11	
		7 ft. thick		2	3	5	8	13		
Breaching*	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep									
	Necessary number of hits			12	17	22	33			
	Total number of rounds			18	26	66	300			
	Total complete round weight (lb.)			2,400	3,400	8,700	39,400			
	No. of rds. fired at each point of aim			3	13	33				
	Deflection difference between successive aiming points (ft.)			2	6	6				
	No. of different aiming points			6	2	2	1			
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep									
	Necessary number of hits			21	28	37	55			
	Total number of rounds			24	42	100	550			
	Total complete round weight (lb.)			3,200	5,500	13,100	72,200			
	No. of rds. fired at each point of aim			4	21	50				
	Deflection difference between successive aiming points (ft.)			2	6	6				
	No. of different aiming points			6	2	2	1			

* Replace about one-fifth of rounds with HE shell, superquick fuzed, against reinforced concrete.

Table LXV. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 8-in. Howitzer M2 Firing HE Shell M106 with CP Fuze M78

Projectile weight: 200.34 lb. Complete round weight: 228.52 lb. Muzzle velocity: 1,950 f/s

Range (yd.)			0	1,000	3,000	5,000	7,500	10,000	12,500	15,000
Terminal velocity (f/s)			1,950	1,820	1,580	1,370	1,160	1,060	1,030	1,030
Probability of hitting target 1 yd. square in any one round							0.060	0.018	0.0056	0.0021
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	4.0	3.7	3.1	2.6	2.1	1.8	1.8	1.8
		Face vertical (ft.)	4.0	3.7	3.1	2.4	1.9	1.4	1.1	
		Face horizontal* (ft.)						1.3	1.4	1.5
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	6.0	5.5	4.7	4.0	3.5	3.2	3.1	3.1
		Face vertical (ft.)	6.0	5.5	4.7	4.0	3.3	2.8	2.4	
		Face horizontal* (ft.)						2.7	2.7	2.9
	Volume of concrete excavated by first round (cu. ft.)			50	40	30	22			
	Number of rounds falling in circle of 1.67 yd. diameter necessary to perforate concrete	3 ft. thick		1	1	1	1	1	1	1
		5 ft. thick		1	2	4	6	7	8	8
		7 ft. thick		3	5	8	11	14	15	15
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep									
	Necessary number of hits			12	16	21	30	35		
	Total number of rounds			15	24	50	250	440		
	Total complete round weight (lb.)			3,400	5,500	11,400	57,100	100,500		
	No. of rds. fired at each point of aim			5	8	25	125			
	Deflection difference between successive aiming points (ft.)			4	4	6	6			
	No. of different aiming points			3	3	2	2	1		
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep									
	Necessary number of hits			21	27	35	50	55		
	Total number of rounds			24	39	80	390	650		
	Total complete round weight (lb.)			5,500	8,900	18,300	89,100	148,500		
	No. of rds. fired at each point of aim			8	13	40	195			
	Deflection difference between successive aiming points (ft.)			4	4	6	6			
	No. of different aiming points			3	3	2	2	1		

Table LXVI. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 8-in. Gun M1 Firing HE Shell M103 with CP Fuze M78

Projectile weight: 240.34 lb. Complete round weight: 338.34 lb. Muzzle velocity: 2,850 f/s

Range (yd.)			0	10,000	12,000	15,000	19,000	23,000	27,000	31,000
Terminal velocity (f/s)			2,850	1,920	1,750	1,520	1,290	1,160	1,120	1,150
Probability of hitting target 1 yd. square in any one round					0.0088	0.0035	0.0010	0.00024		
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	8.0			3.5	2.7	2.5	2.3	2.4
		Face vertical (ft.)	8.0			3.0	2.0	1.4		
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	11.6			5.2	4.5	3.8	3.7	3.8
		Face vertical (ft.)	11.6			4.9	3.7	2.9		
	Volume of concrete excavated by first round (cu. ft.)			75	65	55				
	Number of rounds falling in circle of 1.67 yd. diameter necessary to perforate concrete	3 ft. thick		1	1	1	1	1	1	1
		5 ft. thick		1	2	3	4	6	7	
		7 ft. thick		2	3	5	8	11	12	
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep									
	Necessary number of hits			8	10					
	Total number of rounds			290	625					
	Total complete round weight (lb.)			98,000	211,000					
	No. of rds. fired at each point of aim									
	Deflection difference between successive aiming points (ft.)									
	No. of different aiming points			1	1					
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep									
	Necessary number of hits			14	16					
	Total number of rounds			475	1,000					
	Total complete round weight (lb.)			161,000	338,000					
	No. of rds. fired at each point of aim									
	Deflection difference between successive aiming points (ft.)									
	No. of different aiming points			1	1					

Table LXVII. Penetration Data—Class A Reinforced Concrete (Compressive Strength 5,000 psi); 240-mm Howitzer M1 Firing HE Shell M114 with CP Fuze M78

Projectile weight: 360.34 lb. Complete round weight: 438.59 lb. Muzzle velocity: 2,300 f/s

Range (yd.)			0	8,000	10,000	12,500	15,000	19,000	23,000
Terminal velocity (f/s)			2,300			1,240	1,120	1,080	1,110
Probability of hitting target 1 yd. square in any one round					0.0068	0.0034	0.0019	0.0009	
Single perforation	Penetration depth of one round into thick concrete	Face normal to angle of fall (ft.)	7.0			3.1	2.7	2.6	2.7
		Face vertical (ft.)	7.0			2.5	1.9	1.2	
		Face horizontal* (ft.)					2.3	2.7	
	Thickness of concrete perforated	Face normal to angle of fall (ft.)	9.7			4.9	4.4	4.1	4.4
		Face vertical (ft.)	9.7			4.2	3.7		
		Face horizontal* (ft.)					3.6	4.1	
	Volume of concrete excavated by first round (cu. ft.)					45			
	Number of rounds falling in circle of 2 yd. diameter necessary to perforate concrete	3 ft. thick		1	1	1	1	1	1
		5 ft. thick		1	2	3	5	5	5
		7 ft. thick		2	3	5	9	10	10
Breaching	Concrete wall 10 ft. high, 6 ft. thick; breach 12 ft. wide, 7 ft. deep								
	Necessary number of hits			10	12				
	Total number of rounds			255	530				
	Total complete round weight (lb.)			112,000	232,000				
	No. of rds. fired at each point of aim								
	Deflection difference between successive aiming points (ft.)								
	No. of different aiming points			1	1	1			
	Concrete wall 10 ft. high, 10 ft. thick; breach 12 ft. wide, 6 ft. deep								
	Necessary number of hits			16	20				
	Total number of rounds			385	880				
	Total complete round weight (lb.)			169,000	386,000				
	No. of rds. fired at each point of aim								
	Deflection difference between successive aiming points (ft.)								
	No. of different aiming points					1			

* High angle fire to be used against horizontal targets. Zone 3 charge for 19,000-yd. range; zone 2, for 15,000-yd. range.

Section VI. ARTILLERY REDUCTION OF NATURAL ROCK FORMATIONS

81. Penetration and Demolition

a. Normal Impact. A single projectile, on normal impact on a vertical rock face, produces a shallow crater, spalling off a comparatively thin layer of material over a roughly circular area several feet in diameter. When close range and accurate fire permit, cumulative effect may be obtained by placing additional rounds on the same spot. They deepen the crater without greatly increasing its area until it is roughly conical in form with depth about equal to the radius, and the total volume is four to five times that for a single round. This usually is accomplished in about five rounds, after which the size of the cone is not increased by further firing. Later rounds tend to drill a deep narrow hole in the center of the crater with little external effect. Consequently if the object is production of rubble—for sealing caves, for example—it is undesirable to fire more than five rounds in the same spot.

b. Oblique Impact. With impact at 30 to 60 degrees, the first round usually ricochets and produces a cup-shaped gouge in the rock face. If later rounds can be placed in this crater, they will have nearly normal impact and will bite into the rock, spalling off large quantities of material from the side of the crater away from the gun. The volume of rock displaced by this method is at least as great as that produced by normal impact and may be much greater if the line of fire happens to be nearly parallel to the natural cleavage planes of the rock.

c. Effect of Projectile Type. The high explosive content of a shell does not greatly increase the depth of penetration, nor does it appear to have much effect in shattering rock not already damaged by impact unless the rock is soft and the shell acts as a tamped charge. The high explosive is very useful however in dislodging material which already has been cracked or loosened by the impact and which otherwise might remain in place. For this reason, HE ammunition with the concrete-piercing fuze M78 is very effective because it combines good penetration with a large bursting charge. Even if the shell breaks up on impact, as sometimes happens in hard rock, the resultant low order detonation is adequate to remove the loosened material. An equally effective combination is APC with BD fuze, followed by rounds of HE with CP fuze, in the proportion of 5 to 2. One such series, accurately placed, will usually suffice of close an opening.

d. Edge Effect. Like concrete, rock is less resistant to artillery fire if it has an edge, that is, an unsupported surface, to "break to". Projectiles striking closer than 15 calibers to a free edge—such as a cave mouth—penetrate more deeply and remove more material than they would from an unbroken surface. The effect is best at 8 to 10 calibers from the

edge, in which case two to five times the normal amount of rock ma be demolished.

e. Rubble. Most of the rock shattered by artillery fire remains i sizable pieces weighing from a few pounds to half a ton or more. It i not pulverized nor scattered, but usually drops straight down from th point of impact. Hits just above a cave opening make use of this featur in combination with the edge effect.

82. Rock Characteristics

a. Variation. Penetration and demolition of natural rock appear t be directly related to the compressive strength of the material. The rock mentioned in table LXVIII represent common types, but the compressio strength may vary widely for different formations; for example, i different limestones the strength may be anywhere between 9,000 an 22,000 pounds per square inch. Other types also have wide limits, an the artilleryman seldom will know the exact strength of the rock he i attacking. Consequently the tables given below should be considere merely as a rough guide to show the magnitude of the effects to b expected and the relative power of the various weapons. Demolition i influenced also by other characteristics of the rock such as stratification brittleness, or direction of cleavage.

b. Weathering. The depths of penetration and volumes of rubbl tabulated below pertain to rock in solid beds, unbroken by seams o faults. This is the least favorable condition, so the values given probabl are conservative. Most cave construction will be in strata near the surfac where the rock may be severely weathered. Heavy weathering result in many cracks and fissures and, where such conditions exist, the termina effect of artillery fire may be two or three times that indicated for un weathered rock.

83. Tables

a. Penetration. Based on actual firings at proving grounds, depth of penetration of artillery projectiles into various kinds of rock are shown in table LXVIII. Depth of penetration is measured in line with the trajectory and normal impact is assumed. All HE ammunition is fuzed with CP fuze M78.

b. Volume Demolished. The volume of rock broken and displaced by the first hit is shown in table LXVIII. These data may be used as a measure of effectiveness in sealing caves.

c. Accuracy. Tables of values of probable error are given in table LXIX and number of rounds required for a 90 percent probability of at least one hit are given in table LXX. Probable errors are given in feet on a vertical target; H is the probable error in height and L the probable

error in width. The values listed are for field carriages, but it is believed that the values for self-propelled mounts are essentially the same. The values for number of rounds assume the center of impact to be at the center of the target and hence are in addition to the number of rounds required for registration. If the center of impact is adjusted from observation of five rounds only, the number required is about 20 percent higher.

Table LXVIII. Penetration of Artillery Projectiles into Hard and Soft Rock and Volume of Crater Formed by First Hit

(Values in parentheses are for nondeforming projectiles of the same weight and shape as the projectiles listed.)

Weapon	Ammunition	Range (yd)	Penetration (inches) and crater volume (cu. ft.) removed by first hit			
			Hard rock		Soft rock	
			Penetration (in.)	Crater volume (cu ft)	Penetration (in.)	Crater volume (cu ft)
Howitzer, 75-mm, M1A1, M2, M3.	SHELL, semifixed, HE, M48 charge 4 MV-1250 f/s	0	(7.8)	(0.64)	11.9	1.85
		500	(7.1)	(0.51)	11.0	1.45
		1,000	(6.8)	(0.42)	10.4	1.23
		2,000	6.3	0.34	9.7	1.00
		3,000	6.0	0.29	9.2	0.84
		4,000	5.8	0.25	8.8	0.75
		5,000	5.5	0.22	8.4	0.65
	SHELL, semifixed, HE, M48 charge 2 MV-810 f/s	0	5.0	0.169	7.7	0.49
		500	4.9	0.160	7.5	0.46
		1,000	4.7	0.147	7.3	0.43
		2,000	4.5	0.125	6.9	0.36
		3,000	4.3	0.106	6.5	0.31
Gun, 75-mm, M3, M6, M17.	SHELL, fixed, HE, M48 supercharge MV-1980 f/s	0	(12.3)	(2.54)	(18.8)	(7.3)
		500	(11.5)	(2.07)	(17.6)	(6.0)
		1,000	(10.7)	(1 66)	(16.4)	(4.8)
		2,000	(9.2)	(1.08)	14.2	3.1
		3,000	(8.0)	(0.70)	12.3	2.0
		4,000	(7.0)	(0.47)	10.7	1.37
		5,000	6.3	0.35	9.7	1.00
	PROJECTILE, fixed, APC-T, M61 and M61A1 MV-2030 f/s	0	12.5	2.7	19.1	7.7
		500	11.6	2.2	17.9	6.3
		1,000	10.8	1.75	16.6	5.1
		2,000	9.3	1.12	14.3	3.2
		3,000	8.0	0.70	12.3	2.0
		4,000	6.9	0.44	10.5	1.29
		5,000	6.2	0.33	9.6	0.97

Table LXVIII. Penetration of Artillery Projectiles into Hard and Soft Rock and Volume of Crater Formed by First Hit—Continued

(Values in parentheses are for nondeforming projectiles of the same weight and shape as the projectiles listed.)

Weapon	Ammunition	Range (yd)	Penetration (inches) and crater volume (cu. ft.) removed by first hit			
			Hard rock		Soft rock	
			Penetration (in.)	Crater volume (cu ft)	Penetration (in.)	Crater volume (cu ft)
Gun, 76-mm, M1A1C, M1A2.	SHELL, fixed, HE, M42A1 normal charge MV-2700 f/s	0	(14.3)	(4.0)	(22.0)	(11.6)
		500	(13.3)	(3.2)	(20.0)	(9.4)
		1,000	(12.4)	(2.6)	(19.0)	(7.6)
		2,000	(10.6)	(1.64)	(16.3)	(4.7)
		3,000	(9.0)	(0.99)	(13.7)	(2.9)
		4,000	(7.5)	(0.57)	11.4	1.65
		5,000	(6.2)	(0.32)	9.5	0.94
		6,000	5.4	0.22	8.3	0.62
	PROJECTILE, fixed, APC-T, M62 and M62A1 MV-2600 f/s.	0	16.0	5.6	25.0	16.3
		500	15.1	4.7	23.0	13.6
		1,000	14.1	3.9	22.0	11.2
		2,000	12.3	2.6	18.9	7.4
		3,000	10.6	1.64	16.3	4.7
		4,000	9.0	1.01	13.9	2.9
		5,000	7.6	0.61	11.7	1.77
Gun, 90-mm, M1, M1A1, M2, M3.	SHELL, fixed, HE, M71 MV-2700 f/s.	0	(18.9)	(9.3)	(29.0)	(27.0)
		500	(18.1)	(8.2)	(27.5)	(24.0)
		1,000	(17.2)	(7.0)	(26.0)	(20.0)
		2,000	(15.6)	(5.2)	(24.0)	(15.1)
		3,000	(14.1)	(3.8)	(22.0)	(11.1)
		4,000	(12.6)	(2.7)	(19.3)	(7.9)
		5,000	(11.2)	(1.93)	17.2	4.6
		6,000	(9.8)	(1.31)	15.1	3.8
		7,000	8.8	0.96	13.5	2.8
		8,000	7.7	0.62	11.8	1.81
	PROJECTILE, fixed, APC-T, M82 MV-2800 f/s.	0	19.0	9.4	29.0	27.0
		500	18.2	8.3	28.0	24.0
		1,000	17.3	7.1	27.0	21.0
		2,000	15.7	5.3	24.0	15.3
		3,000	14.1	3.8	22.0	11.1
		4,000	12.6	2.7	19.3	7.9
		5,000	11.2	2.0	17.2	5.9
		6,000	9.8	1.31	15.1	3.8
		7,000	8.8	0.99	13.5	2.9
		8,000	7.8	0.66	12.0	1.9

Table LXVIII. Penetration of Artillery Projectiles into Hard and Soft Rock and Volume of Crater Formed by First Hit—Continued

(Values in parentheses are for nondeforming projectiles of the same weight and shape as the projectiles listed.)

Weapon	Ammunition	Range (yd)	Penetration (inches) and crater volume (cu. ft.) removed by first hit			
			Hard rock		Soft rock	
			Penetration (in.)	Crater volume (cu ft)	Penetration (in.)	Crater volume (cu ft)
Howitzer, 105-mm, M2A1, M4.	SHELL, semifixed, HE, M1 charge 7 MV-1550 f/s.	0	(11.7)	(2.2)	17.9	6.3
		500	(11.0)	(1.82)	16.8	5.3
		1,000	(10.3)	(1.50)	15.8	4.3
		2,000	(9.1)	(1.03)	14.0	3.0
		3,000	(8.1)	(0.74)	12.5	2.1
		4,000	7.7	(0.62)	11.8	1.79
		5,000	7.4	(0.55)	11.3	1.59
		6,000	7.2	(0.51)	11.0	1.47
		7,000	7.0	(0.47)	10.7	1.35
		8,000	6.8	(0.43)	10.4	1.23
	SHELL, semifixed, HE, M1 charge 5 MV-1020 f/s.	0	7.7	0.62	11.8	1.79
		500	7.4	0.57	11.4	1.64
		1,000	7.3	0.53	11.2	1.54
		2,000	7.0	0.47	10.7	1.36
		3,000	6.7	0.41	10.3	1.19
		4,000	6.5	0.37	9.9	1.07
		5,000	6.2	0.33	9.6	0.97
	SHELL, semifixed, HE, M1 charge 3 MV-780 f/s.	0	5.9	0.28	9.0	0.80
		500	5.7	0.26	8.8	0.75
		1,000	5.6	0.24	8.6	0.71
		2,000	5.4	0.22	8.3	0.62
		3,000	5.2	0.192	8.0	0.55
		4,000	5.0	0.173	7.7	0.50
Howitzer, 105-mm, M3.	SHELL, semifixed, HE, M1 charge 5 MV-1020 f/s.	0	7.7	0.62	11.8	1.79
		500	7.4	0.57	11.4	1.64
		1,000	7.3	0.53	11.2	1.54
		2,000	7.0	0.47	10.7	1.36
		3,000	6.7	0.41	10.3	1.19
		4,000	6.5	0.37	9.9	1.07
		5,000	6.2	0.33	9.6	0.97
	SHELL, semifixed, HE, M1 charge 3 MV-780 f/s.	0	5.9	0.28	9.0	0.80
		500	5.7	0.26	8.8	0.75
		1,000	5.6	0.24	8.6	0.71
		2,000	5.4	0.22	8.3	0.62
		3,000	5.2	0.192	8.0	0.55
		4,000	5.0	0.173	7.0	0.50

Table LXVIII. Penetration of Artillery Projectiles into Hard and Soft Rock an Volume of Crater Formed by First Hit—Continued

(Values in parentheses are for nondeforming projectiles of the same weight an shape as the projectiles listed.)

Weapon	Ammunition	Range (yd)	Penetration (inches) and crater volume (cu. ft.) removed by first hit			
			Hard rock		Soft rock	
			Penetration (in.)	Crater volume (cu ft)	Penetration (in.)	Crater volume (cu ft)
Howitzer, 155-mm, M1.	SHELL, HE, M107 charge 7 MV-1850 f/s.	0	(19.2)	(9.7)	(29.0)	(28.0)
		500	(18.5)	(8.7)	(28.0)	(25.0)
		1,000	(17.8)	(7.7)	(27.0)	(22.0)
		2,000	(16.3)	(6.0)	(25.0)	(17.3)
		3,000	(15.0)	(4.6)	23.0	13.3
		4,000	(13.7)	(3.5)	21.0	10.2
		5,000	(12.7)	(2.9)	19.0	8.3
		6,000	(11.7)	(2.2)	17.9	6.3
		7,000	11.2	1.91	17.1	5.5
		8,000	10.6	1.63	16.2	4.7
		9,000	10.5	1.57	16.0	4.5
		10,000	10.3	1.50	15.8	4.3
		12,000	10.2	1.47	15.7	4.3
	SHELL, HE, M107 charge 5 MV-1220 f/s.	0	(12.7)	(2.8)	19.4	8.1
		500	(12.2)	(2.5)	18.6	7.2
		1,000	(11.6)	(2.1)	17.8	6.2
		2,000	(10.9)	(1.78)	16.7	5.2
		3,000	10.5	1.59	16.1	4.6
		4,000	10.2	1.45	15.6	4.2
		5,000	10.0	1.34	15.2	3.9
		6,000	9.7	1.24	14.8	3.6
		7,000	9.6	1.18	14.6	3.4
		8,000	9.4	1.12	14.3	3.2
		9,000	9.3	1.09	14.2	3.2
	SHELL, HE, M107 charge 3 MV-880 f/s.	0	9.1	1.05	14.0	3.0
		500	9.0	1.00	13.8	2.8
		1,000	8.8	0.95	13.5	2.7
		2,000	8.6	0.86	13.1	2.5
		3,000	8.3	0.78	12.7	2.3
		4,000	8.1	0.72	12.4	2.1
		5,000	7.9	0.68	12.1	1.96
		6,000	7.7	0.63	11.8	1.83
Gun, 155-mm, M2.	SHELL, HE, M101 supercharge MV-2800 f/s.	0	(29.0)	(34.0)	(45.0)	(97.0)
		500	(28.0)	(31.0)	(43.5)	(89.0)
		1,000	(27.0)	(28.0)	(42.0)	(82.0)
		2,000	(26.0)	(24.0)	(40.0)	(68.0)
		3,000	(24.0)	(19.4)	(37.0)	(56.0)

Table LXVIII. Penetration of Artillery Projectiles into Hard and Soft Rock and Volume of Crater Formed by First Hit—Continued

(Values in parentheses are for nondeforming projectiles of the same weight and shape as the projectiles listed.)

Weapon	Ammunition	Range (yd)	Penetration (inches) and crater volume (cu ft) removed by first hit			
			Hard rock		Soft rock	
			Penetration (in.)	Crater volume (cu ft)	Penetration (in.)	Crater volume (cu ft)
Gun, 155-mm, M2—Contd.	SHELL, HE, M101 supercharge MV-2800 f/s.	4,000	(23.0)	(15.9)	(35.0)	(46.0)
		5,000	(22.0)	(12.9)	(32.5)	(38.0)
		6,000	(20.0)	(10.3)	(30.0)	(30.0)
		7,000	(18.4)	(8.4)	(28.0)	(24.3)
		8,000	(16.8)	(6.5)	(26.0)	(18.8)
		9,000	(15.5)	(5.1)	24.0	14.7
		10,000	(14.2)	(4.0)	22.0	11.4
		12,000	(12.1)	(2.5)	18.6	7.1
		13,000	11.6	2.1	17.8	6.2
		14,000	11.1	1.86	17.0	5.4
	SHELL, HE, M101 normal charge MV-2100 f/s.	0	(22.0)	(14.2)	(33.0)	(41.0)
		500	(21.0)	(12.9)	(32.0)	(37.0)
		1,000	(20.0)	(11.6)	(31.0)	(33.0)
		2,000	(18.9)	(9.2)	(29.0)	(27.0)
		3,000	(17.4)	(7.3)	(27.0)	(21.0)
		4,000	(16.1)	(5.7)	(25.0)	16.4
		5,000	(14.8)	(4.0)	23.0	13.0
		6,000	(13.5)	(3.4)	21.0	9.7
		7,000	(12.6)	(2.8)	19.4	7.9
		8,000	(11.6)	(2.1)	17.7	6.1
		9,000	(11.2)	(1.89)	17.1	5.5
		10,000	(10.7)	(1.68)	16.4	4.8
		12,000	10.5	1.58	16.1	4.6
	PROJECTILE, AP, M112 supercharge.	0	30.0	37.0	46.0	106.0
		500	29.0	34.0	44.5	97.0
		1,000	28.0	31.0	43.0	88.0
		2,000	26.0	25.0	40.0	73.0
		3,000	25.0	20.0	38.0	59.0
		4,000	23.0	16.3	35.0	47.0
		5,000	21.2	13.2	32.5	38.0
		6,000	19.4	10.0	30.0	29.0
		7,000	17.9	8.0	27.5	23.2
		8,000	16.4	6.0	25.0	17.4
		9,000	15.1	5.3	23.0	14.0
		10,000	13.8	3.6	21.0	10.5
		12,000	12.1	2.4	18.5	7.0
		13,000	11.7	2.16	17.8	6.3
		14,000	11.2	1.91	17.1	5.5

Table LXVIII. Penetration of Artillery Projectiles into Hard and Soft Rock and Volume of Crater Formed by First Hit—Continued

(Values in parentheses are for nondeforming projectiles of the same weight and shape as the projectiles listed.)

Weapon	Ammunition	Range (yd)	Penetration (inches) and crater volume (cu ft) removed by first hit			
			Hard rock		Soft rock	
			Penetration (in.)	Crater volume (cu ft)	Penetration (in.)	Crater volume (cu ft)
Howitzer, 8-in., M2.	SHELL, HE, M106 charge 7 MV-1950 f/s.	0	(26.0)	(24.0)	(40.0)	(69.0)
		500	(25.0)	(21.7)	(38.5)	(63.0)
		1,000	(24.0)	(19.4)	(37.0)	(56.0)
		2,000	(23.0)	(15.7)	(35.0)	(46.0)
		3,000	(21.2)	(13.0)	(32.5)	(38.0)
		4,000	(19.5)	(10.2)	30.0	29.0
		5,000	(18.2)	(8.5)	28.0	24.1
		6,000	(16.9)	(6.7)	26.0	19.3
		7,000	(16.5)	(5.7)	24.5	16.5
		8,000	(15.1)	(4.7)	23.0	13.7
		9,000	(14.6)	(4.3)	22.5	12.4
		10,000	(14.1)	(3.8)	22.0	11.1
		12,000	(13.9)	(3.65)	21.6	10.7
		13,000	(13.8)	(3.6)	21.3	10.4
		14,000	13.7	3.5	21.0	10.1
		15,000	13.9	3.7	21.5	10.5
		18,000	(14.4)	(4.1)	22.0	11.8
	SHELL, HE, M106 charge 5 MV-1380 f/s.	0	(18.3)	(8.4)	28.0	24.0
		500	(17.6)	(7.5)	27.0	21.4
		1,000	(16.8)	(6.5)	26.0	18.8
		2,000	(15.6)	(5.2)	24.0	15.1
		3,000	(14.9)	(4.5)	23.0	13.1
		4,000	(14.1)	(3.8)	22.0	11.1
		5,000	13.8	3.5	21.0	10.3
		6,000	13.4	3.3	20.0	9.5
		7,000	13.2	3.15	20.0	9.1
		8,000	13.0	3.0	19.9	8.7
		9,000	12.9	2.8	19.8	8.6
		10,000	12.8	2.9	19.7	8.4
		12,000	13.0	3.0	19.9	8.7
	SHELL, HE, M106 charge 3 MV-1000 f/s.	0	13.3	3.2	20.0	9.3
		500	13.1	3.1	19.9	8.9
		1,000	12.9	2.9	19.8	8.5
		2,000	12.5	2.7	19.2	7.8
		3,000	12.3	2.5	18.8	7.3
		4,000	11.9	2.3	18.3	6.7
		5,000	11.7	2.2	18.0	6.4
		6,000	11.5	2.1	17.6	6.0
		7,000	11.4	2.03	17.45	5.9
		8,000	11.3	1.98	17.3	5.7

Table LXVIII. Penetration of Artillery Projectiles into Hard and Soft Rock and Volume of Crater Formed by First Hit—Continued

(Values in parentheses are for nondeforming projectiles of the same weight and shape as the projectiles listed.)

Weapon	Ammunition	Range (yd)	Penetration (inches) and crater volume (cu ft) removed by first hit			
			Hard rock		Soft rock	
			Penetration (in.)	Crater volume (cu ft)	Penetration (in.)	Crater volume (cu ft)
Gun, 8-in., M1.	SHELL, HE, M103 supercharge MV-2850 f/s.	0	(45.0)	(128.0)	(70.0)	(370.0)
		500	(44.5)	(122.0)	(68.5)	(350.0)
		1,000	(44.0)	(115.0)	(67.0)	(330.0)
		2,000	(42.0)	(103.0)	(65.0)	(300.0)
		3,000	(40.5)	(92.0)	(62.5)	(270.0)
		4,000	(39.0)	(81.0)	(60.0)	(240.0)
		5,000	(37.5)	(73.0)	(57.5)	(214.0)
		6,000	(36.0)	(64.0)	(55.0)	(184.0)
		7,000	(34.5)	(57.0)	(52.5)	(163.0)
		8,000	(33.0)	(49.0)	(50.0)	(141.0)
		9,000	(31.5)	(43.0)	(48.0)	(125.0)
		10,000	(30.0)	(37.0)	(46.0)	(108.0)
		12,000	(27.6)	(30.1)	(41.4)	(87.0)
		13,000	(26.4)	(26.6)	40.6	(77.0)
		14,000	(25.2)	(23.1)	38.8	67.0
		15,000	(24.0)	(19.6)	37.0	57.0
		18,000	(21.6)	(14.4)	33.6	41.0
		20,000	(20.0)	(10.8)	31.0	31.0
		21,000	(19.0)	(9.9)	30.0	29.0
	SHELL, HE, M103 normal charge MV-2600 f/s.	0	(41.0)	(98.0)	(64.0)	(280.0)
		500	(40.5)	(93.0)	(62.5)	(265.0)
		1,000	(40.0)	(87.0)	(61.0)	(250.0)
		2,000	(38.0)	(77.0)	(59.0)	(220.0)
		3,000	(36.5)	(69.0)	(56.5)	(192.0)
		4,000	(35.0)	(60.0)	(54.0)	(174.0)
		5,000	(33.5)	(54.0)	(52.0)	(155.0)
		6,000	(32.0)	(47.0)	(50.0)	(135.0)
		7,000	(31.0)	(41.0)	(47.5)	(119.0)
		8,000	(30.0)	(35.0)	(45.0)	(102.0)
		9,000	(28.5)	(31.0)	(43.0)	(89.0)
		10,000	(27.0)	(26.0)	(41.0)	(76.0)
		12,000	(25.0)	(20.0)	38.0	59.0
		13,000	(24.6)	(16.7)	36.2	52.0
		14,000	(22.3)	(13.3)	34.6	45.0
		15,000	(21.0)	(12.3)	33.0	39.0
		18,000	(19.1)	(9.9)	30.0	29.0
		20,000	(18.1)	(8.1)	28.0	23.0
		21,000	(17.7)	(7.7)	27.0	22.0

Table LXVIII. Penetration of Artillery Projectiles into Hard and Soft Rock and Volume of Crater Formed by First Hit—Continued

(Values in parentheses are for nondeforming projectiles of the same weight and shape as the projectiles listed.)

Weapon	Ammunition	Range (yd)	Penetration (inches) and crater volume (cu ft) removed by first hit			
			Hard rock		Soft rock	
			Penetration (in.)	Crater volume (cu ft)	Penetration (in.)	Crater volume (cu ft)
Gun, 8-in., M1—Contd.	SHELL, HE, M103 reduced charge MV-2100 f/s.	0	(33.0)	(51.0)	(51.0)	(149.0)
		500	(32.5)	(48.0)	(50.5)	(140.0)
		1,000	(32.0)	(45.0)	(49.0)	(130.0)
		2,000	(31.0)	(39.0)	(47.0)	(113.0)
		3,000	(29.5)	(34.0)	(45.0)	(99.0)
		4,000	(28.0)	(29.0)	(43.0)	(85.0)
		5,000	(26.5)	(26.0)	(41.0)	(74.0)
		6,000	(25.0)	(22.0)	39.0	63.0
		7,000	(24.0)	(19.0)	37.0	55.0
		8,000	(23.0)	(16.1)	35.0	46.0
		9,000	(21.9)	(14.3)	33.6	42.0
		10,000	(20.9)	(12.7)	32.2	37.0
		12,000	(18.9)	(9.5)	29.4	28.0
		13,000	(17.9)	(7.9)	28.0	23.0
		14,000	(17.7)	7.6	27.6	22.0
		15,000	(17.6)	7.4	27.2	21.0
		18,000	(17.3)	7.1	26.0	20.0
Howitzer, 240-mm, M1.	SHELL, HE, M114 charge 4 MV-2300 f/s.	0	(41.0)	(92.0)	(62.0)	(270.0)
		500	(40.0)	(86.0)	(61.0)	(250.0)
		1,000	(39.0)	(80.0)	(60.0)	(230.0)
		2,000	(37.0)	(70.0)	(57.0)	(200.0)
		3,000	(35.5)	(62.0)	(54.5)	(177.0)
		4,000	(34.0)	(53.0)	(52.0)	(153.0)
		5,000	(32.5)	(46.0)	(49.5)	(133.0)
		6,000	(31.0)	(39.0)	(47.0)	(113.0)
		7,000	(29.0)	(34.0)	(44.5)	(97.0)
		8,000	(27.0)	(28.0)	42.0	81.0
		9,000	(26.0)	(24.0)	40.0	71.0
		10,000	(25.0)	(21.0)	38.0	60.0
		12,000	(22.0)	(15.5)	34.0	45.0
		13,000	(21.2)	(13.8)	32.6	41.0
		14,000	(20.6)	(12.2)	31.3	36.0
		15,000	(20.0)	(10.6)	30.0	31.0

Table LXVIII. Penetration of Artillery Projectiles into Hard and Soft Rock and Volume of Crater Formed by First Hit—Continued

(Values in parentheses are for nondeforming projectiles of the same weight and shape as the projectiles listed.)

Weapon	Ammunition	Range yd)	Penetration (inches) and crater volume (cu ft) removed by first hit: Hard rock, Penetration (in.)	Hard rock, Crater volume (cu ft)	Soft rock, Penetration (in.)	Soft rock, Crater volume (cu ft)
Howitzer, 240-mm, M1—Contd.	SHELL, HE, M114 charge 3	0	(36.0)	(62.0)	(55.0)	(180.0)
		500	(35.0)	(58.0)	(53.5)	(168.0)
		1,000	(34.0)	(54.0)	(52.0)	(156.0)
		2,000	(32.0)	(47.0)	(50.0)	(134.0)
	MV–2020 f/s.	3,000	(30.5)	(41.0)	(47.5)	(116.0)
		4,000	(29.0)	(34.0)	(45.0)	(98.0)
		5,000	(27.5)	(29.0)	42.5	84.0
		6,000	(26.0)	(24.0)	40.0	70.0
		7,000	(24.5)	(20.9)	38.0	61.0
		8,000	(23.0)	(17.6)	36.0	51.0
		9,000	(22.0)	(15.2)	34.0	44.0
		10,000	(21.0)	(12.8)	32.0	37.0
		12,000	(19.3)	(9.9)	30.0	29.0
		13,000	(19.1)	(9.6)	29.5	28.0
		14,000	18.9	9.2	29.0	27.0
	SHELL, HE, M114 charge 2	0	(31.0)	(40.0)	(47.0)	(115.0)
		500	(30.0)	(37.0)	(46.0)	(106.0)
		1,000	(29.0)	(34.0)	(45.0)	(98.0)
		2,000	(28.0)	(29.0)	42.0	84.0
	MV–1740 f/s.	3,000	(26.5)	(25.0)	40.0	72.0
		4,000	(25.0)	(21.0)	38.0	60.0
		5,000	(23.5)	(17.8)	36.0	51.0
		6,000	(22.0)	(14.5)	34.0	42.0
		7,000	(21.5)	(13.7)	33.0	40.0
		8,000	(21.0)	(12.9)	32.0	37.0
		9,000	(19.8)	(10.9)	30.5	32.0
		10,000	18.6	8.9	29.0	26.0
		12,000	18.6	7.9	28.0	20.0
		13,000	18.7	9.0	29.0	26.0
	SHELL, HE, M114 charge 1	0	(26.0)	(25.0)	41.0	74.0
		500	(25.5)	(23.5)	39.5	68.0
		1,000	(25.0)	(22.0)	38.0	62.0
		2,000	(24.0)	(18.2)	36.0	53.0
	MV–1500 f/s.	3,000	(22.5)	(15.6)	34.0	45.0
		4,000	(21.0)	(12.9)	32.0	37.0
		5,000	(19.5)	(11.0)	30.5	32.0
		6,000	(18.8)	(9.2)	29.0	27.0
		7,000	17.7	7.7	27.0	22.0

Table LXIX. Vertical Probable Error (H) and Lateral Probable Error (L) in Feet for 57-mm Rifle to 240-mm Howitzer

Weapon	Ammunition*		MV f/s	1,000 H	1,000 L	2,000 H	2,000 L	3,000 H	3,000 L	4,000 H	4,000 L	5,000 H	5,000 L	6,000 H	6,000 L	7,000 H	7,000 L	8,000 H	8,000 L	9,000 H	9,000 L	10,000 H	10,000 L
57-mm rifle M18, T15E13	Cartridge, HE, M306		1200	1.2	1.8	5.0	3.8	19.0	6.2	73.0	8.8												
75-mm Howitzer, M1A1, M2, M3	Shell semi-fixed, HE, M48 Charge	1	700	6.0	0.7	22.0	2.0	52.0	3.7	123.0	5.8												
		2	810	3.9	2.3	13.0	4.1	28.0	5.3	56.0	6.0	113.0	6.1										
		3	950	2.4	1.9	8.0	3.6	17.0	5.1	31.0	6.3	53.0	7.3	93.0	8.1								
		4	1250	1.3	2.5	4.0	4.7	8.1	6.6	14.0	8.2	22.0	9.5	33.0	11.0	50.0	11.0	78.0	12.0	124.0	12.0		
75-mm rifle T21, M20	Cartridge, HE, M309		990	1.1	2.0	6.0	4.1	15.0	6.0	30.0	8.0	55.0	9.9	97.0	12.0								
75-mm gun M3, M6, M17	Shell, fixed, HE, M48 Charge	R	960	0.3	1.0	2.5	2.2	6.7	3.5	13.0	5.1	25.0	6.8	48.0	8.8								
		N	1520	0.1	1.1	1.1	2.3	3.1	3.7	5.9	5.1	9.7	6.6	16.0	8.2	27.0	10.0	50.0	11.0	97.0	13.0	160.0	15.0
		S	1980	0.7	1.1	2.2	2.2	4.4	3.4	7.5	4.7	11.0	5.9	16.0	7.2	23.0	8.0	32.0	10.0	42.0	11.0	54.0	12.0
76-mm gun M1A1C, M1A2	Shell, fixed, HE, M42A1 Charge	R	1550	0.3	1.1	2.1	2.3	5.3	3.6	9.9	5.0	17.0	6.5	27.0	9.0	44.0	11.0	74.0	13.0				
		N	2700	0.1	0.5	0.7	1.1	1.9	1.8	3.8	2.5	6.2	3.3	9.2	4.1	14.0	5.0	21.0	6.0	31.0	7.0	46.0	8.0
90-mm gun M3	Shell, fixed, HE, M71		2700	0.4	0.8	1.2	1.4	2.6	2.2	4.4	3.0	6.8	3.9	10.0	4.8	15.0	6.0	22.0	7.0	31.0	8.0	43.0	9.0
105-mm howitzer M2A1, M4	Shell, semi-fixed, HE, M1 Charge	1	650	3.0	0.5	13.0	2.5	37.0	6.0														
		2	710	2.3	0.7	11.0	2.0	26.0	3.6	61.0	5.8												
		3	780	2.2	2.1	8.5	2.3	19.0	3.6	40.0	5.0	80.0	6.5										
		4	875	2.1	0.4	7.3	1.1	15.0	2.1	28.0	3.3	49.0	4.9	85.0	6.7								
		5	1020	2.3	1.3	6.2	2.8	12.0	4.7	20.0	6.8	31.0	9.2	47.0	12.0	72.0	15.0	113.0	18.0				
		6	1235	0.9	0.9	3.1	2.0	6.4	3.4	11.0	5.1	18.0	7.0	27.0	9.2	39.0	11.0	55.0	13.0	78.0	15.0	122.0	18.0
		7	1550	0.5	0.8	1.8	1.8	4.1	2.8	7.2	4.0	11.0	5.3	17.0	6.7	25.0	8.0	35.0	10.0	48.0	11.0	66.0	12.0

* Ammunition: R = reduced, N = normal, S = supercharge.

Table LXIX. Vertical Probable Error (H) and Lateral Probable Error (L) in Feet for 57-mm Rifle to 240-mm Howitzer—Continued

Weapon	Ammunition*		MV f/s	Range in yards																			
				1,000		2,000		3,000		4,000		5,000		6,000		7,000		8,000		9,000		10,000	
				H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
155-mm howitzer M1	Shell, HE, M107	1	680	2.1	0.1	10.0	0.8	24.0	1.9	54.0	3.4												
		2	770	1.6	0.1	5.3	0.5	14.0	1.5	28.0	3.4	54.0	5.5										
		3	880	1.2	0.1	4.2	0.4	8.7	1.1	15.0	2.4	26.0	4.5	44.0	7.5								
	Charge	4	1020	0.7	0.5	2.5	1.1	5.3	1.7	9.8	2.4	15.0	3.3	24.0	4.1	37.0	5.1	57.0	6.1				
		5	1220	1.2	0.4	3.5	0.8	6.7	1.4	11.0	2.0	15.0	2.8	22.0	3.6	31.0	4.5	43.0	5.6	60.0	7.0	84.0	8.
		6	1520	0.6	0.3	1.9	0.6	3.9	1.1	6.6	1.6	10.0	2.3	15.0	3.0	21.0	3.9	28.0	4.9	36.0	5.0	48.0	7.
		7	1850	0.3	0.4	1.1	0.9	2.3	1.4	3.9	2.0	6.1	2.6	8.7	3.3	12.0	4.1	17.0	4.8	23.0	5.0	30.0	7.
155-mm gun M2	Shell, HE, M101 Charge	N	2100	0.5	2.2	1.3	4.2	2.6	6.0	4.3	7.6	6.4	9.1	8.9	10.0	13.0	11.0	18.0	12.0	24.0	13.0	31.0	14.
		S	2800	0.2	2.3	0.6	4.5	1.2	6.8	2.1	8.8	3.1	11.0	4.4	3.0	6.0	4.0	8.0	6.0	10.0	17.0	13.0	19.
8-in. howitzer M2	Shell, HE, M106	1	820	0.6	0.7	2.2	1.9	4.9	3.7	8.7	6.0	17.0	8.8	36.0	12.0								
		2	900	0.8	0.5	2.3	1.6	4.4	3.0	7.1	5.0	12.0	17.4	21.0	10.0	37.0	14.0						
		3	1000	0.5	0.6	1.7	1.5	3.5	2.6	6.0	3.9	9.1	5.4	13.0	7.2	20.0	9.1	33.0	12.0				
	Charge	4	1150	0.8	0.3	2.1	0.8	3.7	1.5	5.8	2.6	8.3	3.8	12.0	5.4	16.0	7.1	21.0	9.2	30.0	12.0	45.0	15.0
		5	1380	0.8	0.2	1.9	0.6	3.4	1.1	5.2	1.8	7.3	2.7	10.0	3.9	14.0	5.1	18.0	6.5	23.0	18.0	30.0	10.0
		6	1640	0.3	0.1	1.0	0.2	2.0	0.5	3.3	0.9	4.9	1.5	6.8	2.2	9.0	3.1	12.0	4.2	15.0	5.0	19.0	6.0
		7	1950	0.2	0.1	0.5	0.2	1.0	0.3	1.7	0.5	2.5	0.8	3.5	1.2	5.0	1.7	6.0	2.3	7.0	3.0	9.0	4.0
8-in. gun M1	Shell, HE, M103 Charge	R	2100	0.0	0.1	0.1	0.3	0.3	0.6	0.6	0.9	1.1	1.2	1.7	1.6	2.5	1.9	3.6	2.3	5.2	2.8	7.4	3.2
		N	2600	0.0	0.1	0.1	0.3	0.3	0.6	0.6	0.9	1.0	1.2	1.6	1.6	2.4	1.9	3.5	2.3	5.0	2.8	7.0	3.2
		S	2850	0.0	0.1	0.1	0.3	0.3	0.6	0.6	0.9	0.9	1.2	1.4	1.6	2.0	1.9	2.8	2.3	3.9	2.8	5.3	3.2
240-mm howitzer M1	Shell, HE, M114	1	1500	0.9	1.0	2.4	2.0	4.5	3.1	7.3	4.2	11.0	5.5	15.0	6.8	19.0	18.1	24.0	9.6	30.0	11.0	37.0	13.0
	Charge	2	1740	0.4	1.3	1.4	2.5	3.0	3.8	5.1	5.0	7.8	6.3	11.0	4.6	15.0	8.9	19.0	10.0	24.0	11.0	30.0	12.0
		3	2020	0.0	2.7	0.5	5.2	1.5	7.4	3.0	9.3	5.0	11.0	7.5	12.0	11.0	13.0	14.0	14.0	18.0	15.0	23.0	15.0
		4	2300	0.0	2.8	0.1	5.3	0.3	7.6	1.2	9.7	2.7	12.0	4.6	13.0	6.9	15.0	9.7	16.0	13.0	16.0	17.0	17.0

* Ammunition: R = reduced, N = normal, S = supercharge.

Table LXX. Number of Rounds Necessary to Have 90 Percent Probability of at Least One Hit on:
Target A—2 feet high, 3 feet wide
Target B—4 feet high, 6 feet wide
Target C—8 feet high, 10 feet wide

Weapon	Ammunition	Target	Range in yards									
			1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
57-mm rifle M18, T15E13	Cartridge, HE, M306	A	10	100	600							
		B	3	25	125	900						
75-mm rifle T21, M20	Cartridge, HE, M309	A	10	130	500							
		B	3	35	125	325						
75-mm gun M3, M6, M17	Shell, fixed, HE, M48	A	6	25	90	200	400					
		B	2	6	25	50	150	250				
76-mm gun M1A1C, M1A2	Shell, fixed, HE, M42A1	A	2	6	25	50	80	200	400			
		B	1	2	6	15	20	50	100	175		
90-mm gun M3	Shell, fixed, HE, M71	A	2	6	35	70	130	300				
		B	1	2	8	15	35	70	125	200		
		C	1	1	3	6	10	25	40	70	100	170
105-mm howitzer M2A1, M4	Shell, semi-fixed, HE, M1	A	4	25	70	150	330					
		B	1	6	15	35	80	140	300			
		C	1	2	6	15	25	50	90	150	200	400
155-mm howitzer M1	Shell, HE, M107	B	1	2	7	10	25	30	70	100	150	250
		C	1	1	2	4	9	15	25	30	50	80
155-mm gun M1	Shell, HE, M101	B	2	6	10	25	50	70	120	175	250	
		C	1	3	5	10	15	40	40	50	70	100
8-in. howitzer M2	Shell, HE, M106	B	1	1	1	4	4	10	12	25	30	50
		C	1	1	1	1	1	3	5	10	10	15

Section VII. ATTACK ON LOG AND EARTH FORTIFICATIONS

84. General

Log and earth fortifications of the type considered in this discussion are built with vertical walls made of several layers of logs or of one or more layers of earth-filled oil drums and with log roofs, the whole covered with earth. They are usually constructed with silhouette so low as to be almost invisible. In some cases, however, where the water table is high, the fortifications would of necessity be mostly above ground level and be more easily seen. The structures are usually well compartmentalized into bays so that a shell detonating in one bay will do a minimum of damage in a bay next to it.

85. Bombing of Log and Earth Fortifications

Bombs are not very effective against this type of target due to the small percentage of hits scored, the resilience of palm-log shoring, the dispersion of personnel in bays, and the high recovery coefficient of these targets. Direct hits are required since near-misses seem to do negligible damage.

86. Artillery and Mortar Attack

a. Fuzing. In artillery attack it is required that the projectile perforate the earth covering and log- or oil-drum-walls and detonate inside the fortifications. Since the materials of the bunkers are rather soft, ordinary HE projectiles may be used without fear of their deforming. A suitable delay fuze is required to bring about the detonation inside. The ordinary SQ-delay PD fuzes attached to most HE projectiles would be satisfactory at ranges for which striking velocities are relatively low. The CP fuze M78 (0.025 sec. delay), where it can be attached to a projectile, may be used at all ranges and must be used at the shorter ranges of certain weapons where the striking velocity is high and an ordinary PD fuze would malfunction.

b. Charts. The data given are limited to giving the maximum ranges at which the various weapon-ammunition combinations will perforate a given thickness of earth and logs. In the case of earth-filled drums, it may be assumed that the steel walls are equivalent to 6 inches of earth in stopping power. Thus, the thickness of earth in a vertical wall would be considered increased by as many times 6 inches as there are layers of steel drums. It appears that soft woods like palm should be as easily

penetrable as earth while hardwoods like oak, ebony, or mahogany wou be equivalent in stopping power to twice their thickness of ear Medium-hard woods like pine or spruce should come in between. The da are given in graphs representing the *thickness of earth or the thickne of logs in the walls penetrated* versus range for the various weapo There is one set of graphs for the attack of vertical walls with low-ang fire and a second set for the attack of roofs with high-angle fire.

c. Type of Attack. (1) *High-angle Fire.* It is clear that, as hig angle fire is practiced, relatively light weapons like the 75-mm a 105-mm howitzers and the 81-mm mortar are of borderline usefulness attacking heavier type roofs of log fortifications. It would seem from t graphs that a well-made bunker or pillbox with 3 layers of logs a say 5 or 6 feet of earth would stand up against any of the light weapo used in high-angle fire. Such targets would be vulnerable to high-ang fire from the 155-mm gun M2, the 155-mm howitzer M1, or the 8-in howitzer M2, but questions of probable errors would come to the for

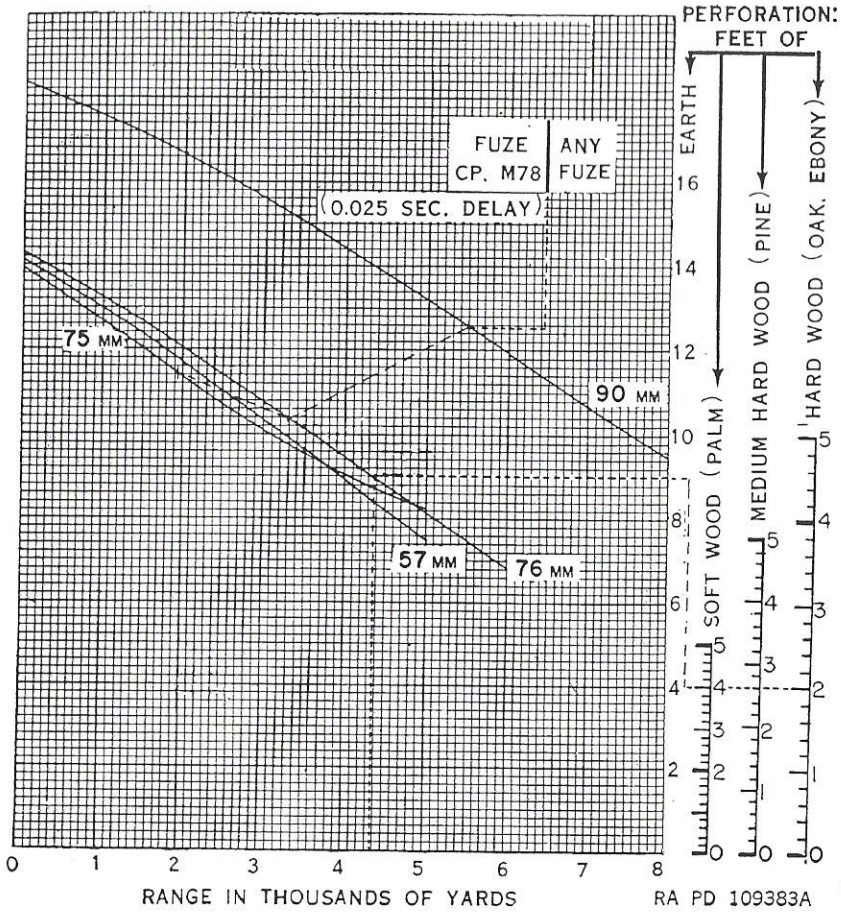
(2) *Direct Fire.* In direct fire against a vertical wall of similar co struction to that of the roof just mentioned, the 57-mm, 75-mm, 76-mm and 90-mm would be effective. The 105-mm howitzer M2A1 also wou be effective but the 105-mm howitzer M3 and the 75-mm howitzer wou be at the limit of their effectiveness at point blank range. Heavie direct-firing guns and howitzers will all defeat such a wall.

87. Rocket Attack

a. 2.36 Inches. It appears from experiments that the 2.36 inch rocke is ineffective against log and earth fortifications. It can be effective only i it enters an embrasure, since it does not have much penetrating power This would require attack from extremely small ranges of approxi mately 15 yards.

b. 4.5 Inches. At a range of 150 feet the 4.5 inch rocket of the M8 series can penetrate about 4 feet of earth and 3 layers of 1 foot pine logs. The spin-stabilized rocket can penetrate about 40 percent greater thickness of log and earth.

c. 5 Inches. When fired from a plane flying low and level at 350 miles per hour the 5-inch HVAR is estimated to penetrate 21 feet of earth at 1,000 yards range and 19 feet at 2,000 yards. The small angle of fall of this rocket limits its use from level flight to the attack of vertical walls. With the BD fuze of 0.02-second delay, there might be some danger of the rocket passing all the way through a bunker before detonating.



90-mm—90-mm guns M1, M1A1, M2, or M3; shell, HE, M71, MV 2700 f/s

76-mm—76-mm guns, M1A1C, or M1A2; shell, HE, M42A1, MV 2700 f/s

75-mm—75-mm guns M3; M6, M17; shell, HE, M48, MV 1980 f/s

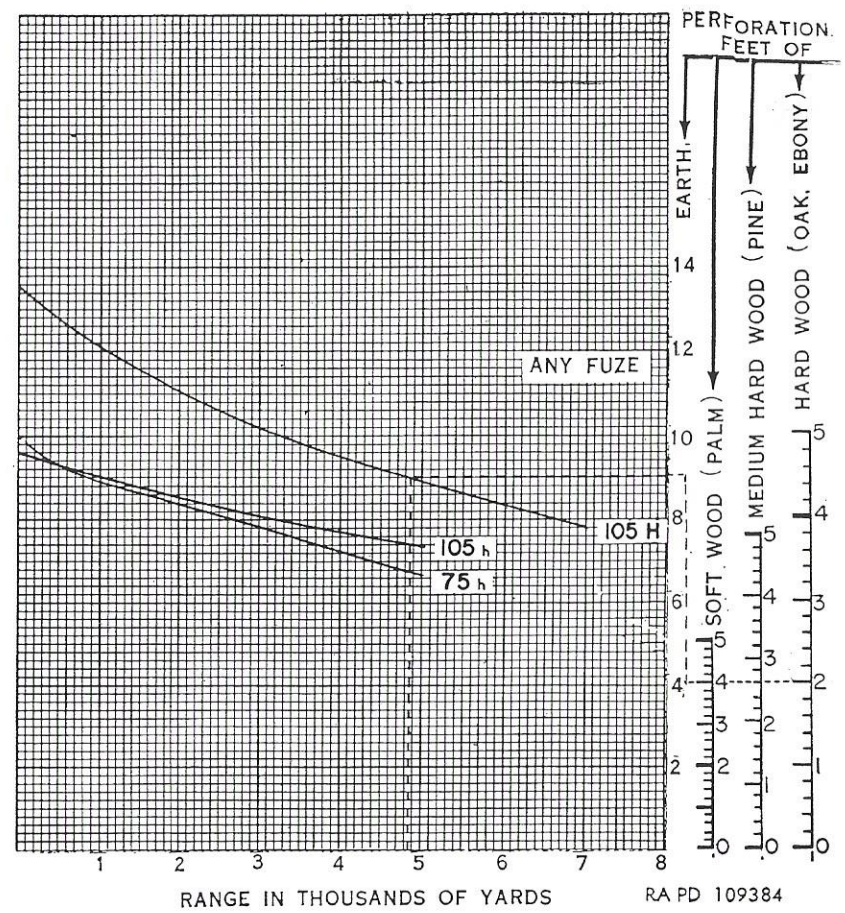
57-mm—57-mm guns M1; projectile, APC-T, M86, MV 2700 f/s

Fuzes: All the above shell may be used with CP, BD, or PD fuzes of 0.025 sec or greater delay, for ranges greater than those indicated by the dash line on the graph. For shorter ranges, only the CP fuze, M78, 0.025 sec delay, may be used.

Example: A bunker has vertical walls consisting of 2 feet of hardwood logs with an embankment 5 feet thick. At what maximum range will the 76-mm gun M1A2 firing shell, HE, M42A1 perforate?

At the right of the diagram it is seen that 2 feet of hardwood logs (lower horizontal dash line) is equivalent to 4 feet of earth. To this 5 feet of earth must be added (vertical dash line). Following the remaining dash lines shows that the maximum range for perforation is 4,350 yards and any fuze may be used.

Figure 137. Perforation of earth and log walls. Maximum ranges for guns 75-mm to 90-mm. Walls vertical, embankment inclination greater than 25°.



105h—105-mm howitzer, M2A1, M4; shell, HE, M1; MV 1550 f/s

105hh—105-mm howitzer, M3, M2A1, M4; shell, HE, M1; MV 1020 f/s

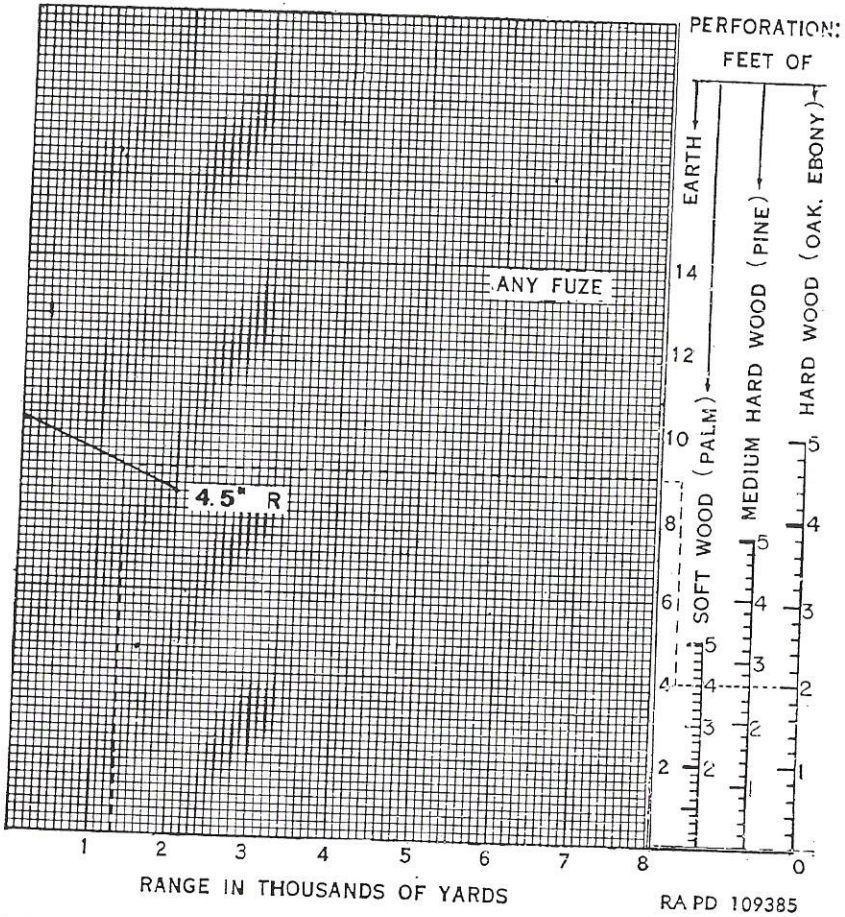
75hh—75-mm howitzer, M1A1, M2, or M3; shell, HE, M48; MV 1250 f/s

Fuzes: All the above shell may be fuzed with any PD or CP delay fuze for all ranges. Use of CP fuze (0.025 sec delay) permissible but not required.

Example: A bunker has vertical walls consisting of 2 feet of hardwood logs with an embankment 5 feet thick. At what maximum range will 105-mm howitzer M2A1 firing shell, HE, M1 (charge 7) perforate?

At the right of the diagram it is seen that 2 feet of hardwood logs is equivalent to four feet of earth (lower horizontal dash line). To this 5 feet of earth must be added (right vertical dash line). Following the remaining dash lines shows that the maximum range for perforation is 4,850 yards.

Figure 138. Perforation of earth and log walls. Maximum ranges for 75-mm and 105-mm howitzers. Walls vertical, embankment inclination greater than 25°.

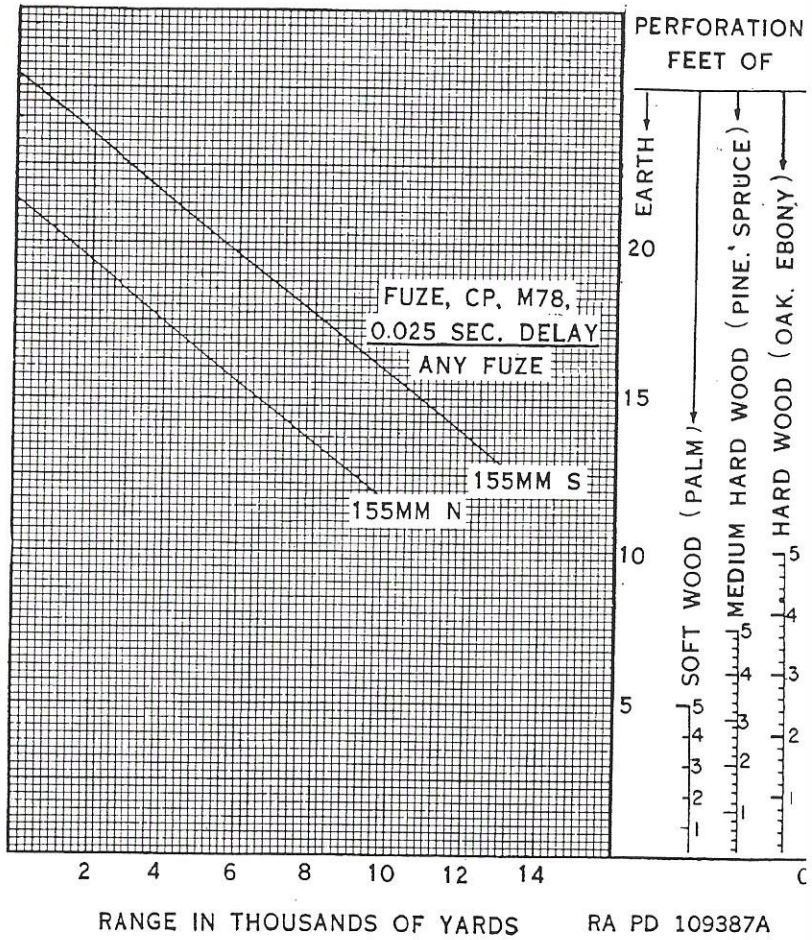


4.5R—4.5-inch HE rocket M16 or M20 with fuze, PD, M81 (or M48A2) or fuze, CP, M78, 0.025 sec delay. The use of the CP fuze is not mandatory.

Example: A bunker has vertical walls consisting of 2 feet of hardwood logs with an embankment 5 feet thick. At what maximum range will the 4.5-inch HE Rocket, M16 or M20 perforate?

At the right of the diagram it is seen that 2 feet of hardwood logs is equivalent to 4 feet of earth (lower horizontal dash line). To this must be added the 5 feet of earth (right vertical dash line). Following the remaining dash lines shows that the maximum range for penetration is 1300 yards.

Figure 139. Perforation of earth and log walls. Maximum range for 4.5 inch spin-type rocket. Walls vertical, embankment inclination greater than 25°.

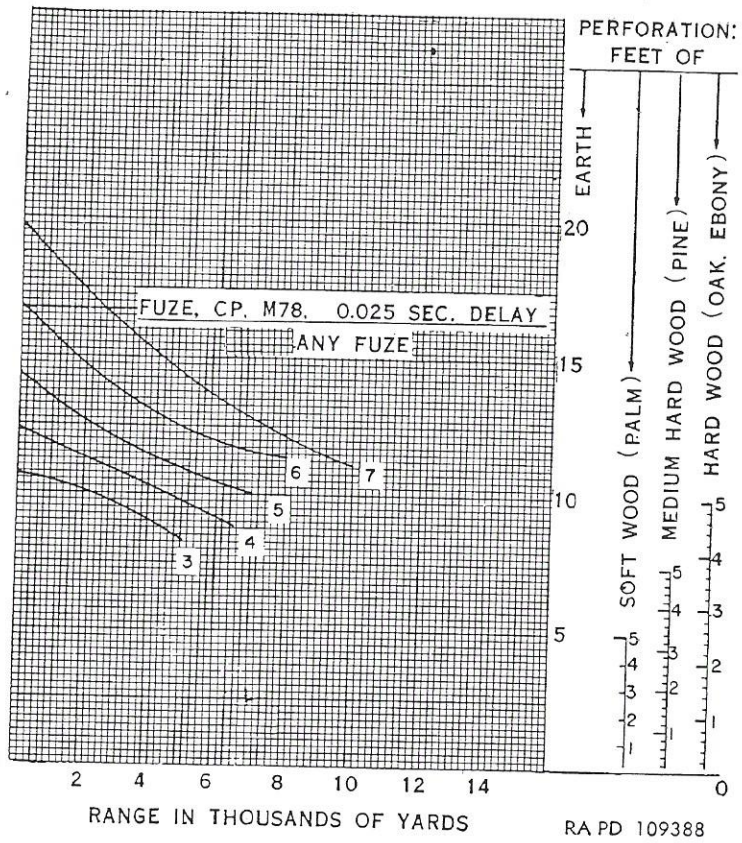


155-mm S—155-mm gun, M2; shell, HE, M101; supercharge

155-mm N—155-mm gun, M2; shell, HE, M101; normal charge

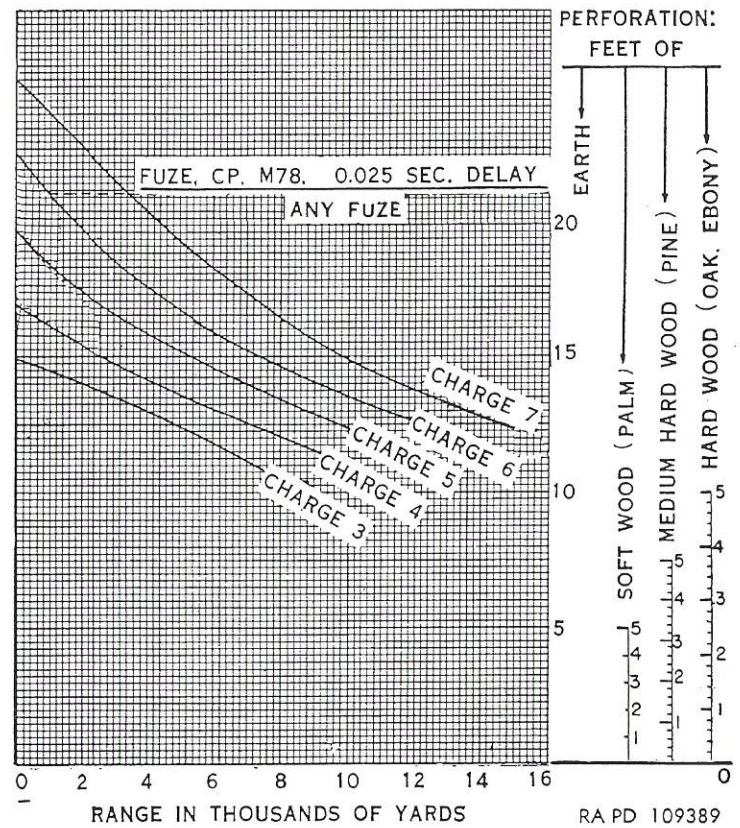
Fuzes: With either of the above rounds, fuze, PD, M51 and mods .05 sec delay or longer or fuze, CP, M78, 0.025 sec delay may be used at all ranges indicated by portions of the curve below the dashed line. Use of fuze, CP, M78, 0.025 sec delay, is mandatory for all ranges indicated by portions of the curves above the dashed line.

Figure 140. Perforation of earth and log walls. 155-mm gun. Walls vertical embankment inclination greater than 25°.



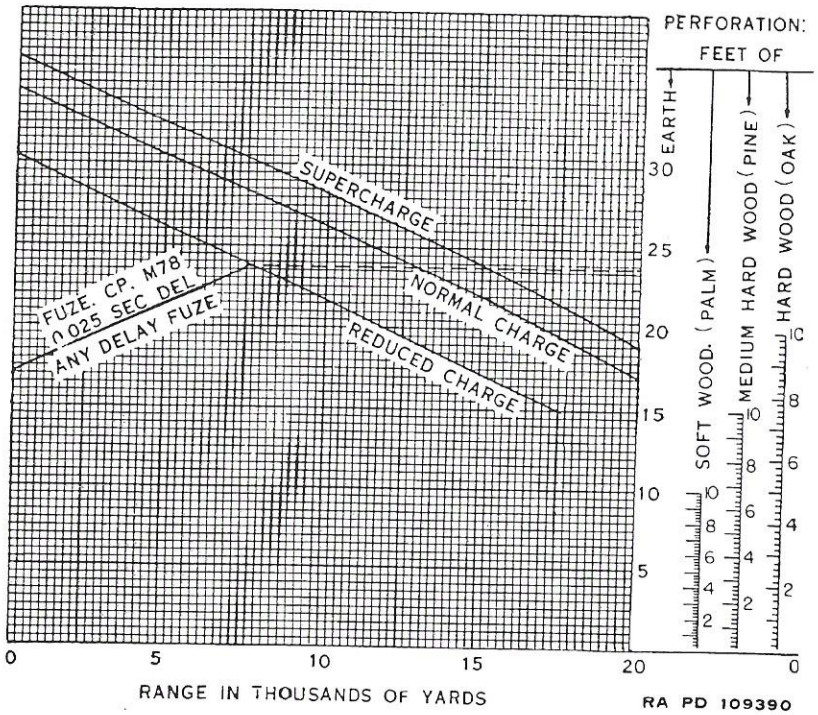
Note: Index figures on the curves refer to zone numbers of the charge. Standard PD or CP delay fuzes may be used at all ranges indicated by portions of the curves below the horizontal dashed line. Use of fuze CP, M78, 0.025 sec delay, is mandatory at ranges indicated by portions of the curves above the dashed line.

Figure 141. Perforation of earth and log walls. Maximum ranges for 155-howitzer, M1 firing shell, HE, M107. Walls vertical, embankment inclination greater than 25°.



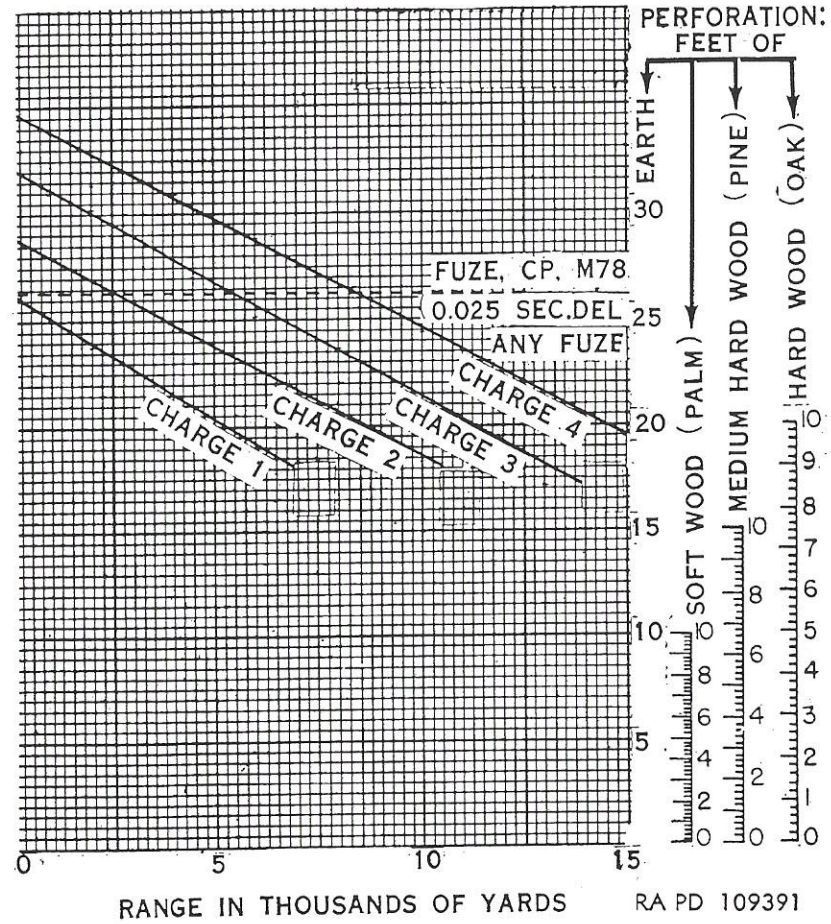
Note: With the above shell, any PD or CP delay fuze may be used at ranges indicated by portions of curves below the horizontal dashed line. Use of fuze CP, M78, 0.025 sec delay, is mandatory for ranges indicated by portions of curves above the dashed line.

Figure 142. Perforation of earth and log walls. Maximum range for 8-inch howitzer, M2 firing HE, shell, M106. Walls vertical, embankment inclination greater than 25°.



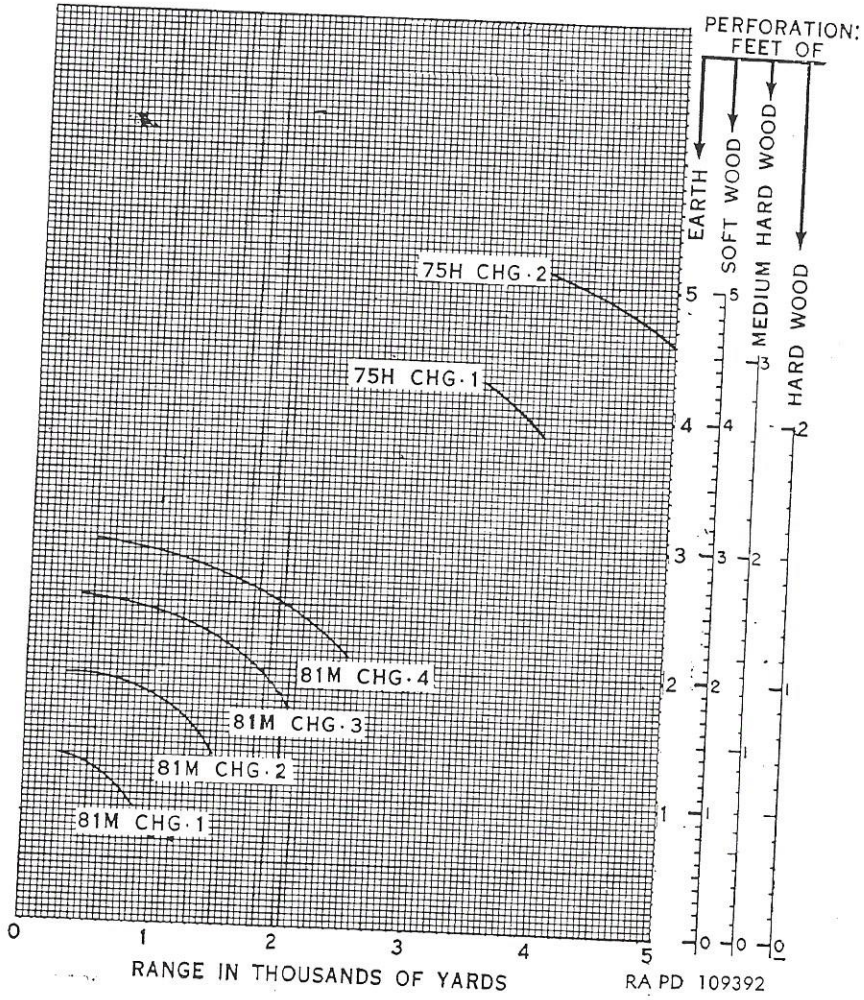
Note: At ranges indicated by portions of the curves above the horizontal dashed line, the use of fuze CP, M78, 0.025 sec delay, is mandatory. At other ranges, any standard PD or CP delay fuze may be used.

Figure 143. Perforation of earth and log walls. Maximum ranges for 8-inch gun M1 firing HE, shell, M103. Walls vertical, embankment inclination greater than 25°.



Note: For ranges indicated by portions of the curves above the horizontal dashed line, the use of fuze CP, M78, 0.025 sec delay, is mandatory. For other ranges, any standard PD or CP delay fuze may be used.

Figure 144. Perforation of earth and log walls. Maximum ranges for 240-mm howitzer M1 firing, HE, shell, M114. Walls vertical, embankment inclination greater than 25°.



75H chg 2—75-mm howitzer, M1A1, M2, or M3 firing shell, HE, M48, w/fuze, PD, M48 (and mods) or fuze CP, M78, 0.025 sec delay; charge 2

75H chg 1—75-mm howitzer, M1A1, M2, or M3 firing shell, HE, M48, w/fuze, PD, 48 (and mods) or fuze, CP, M78, 0.025 sec delay; charge 1

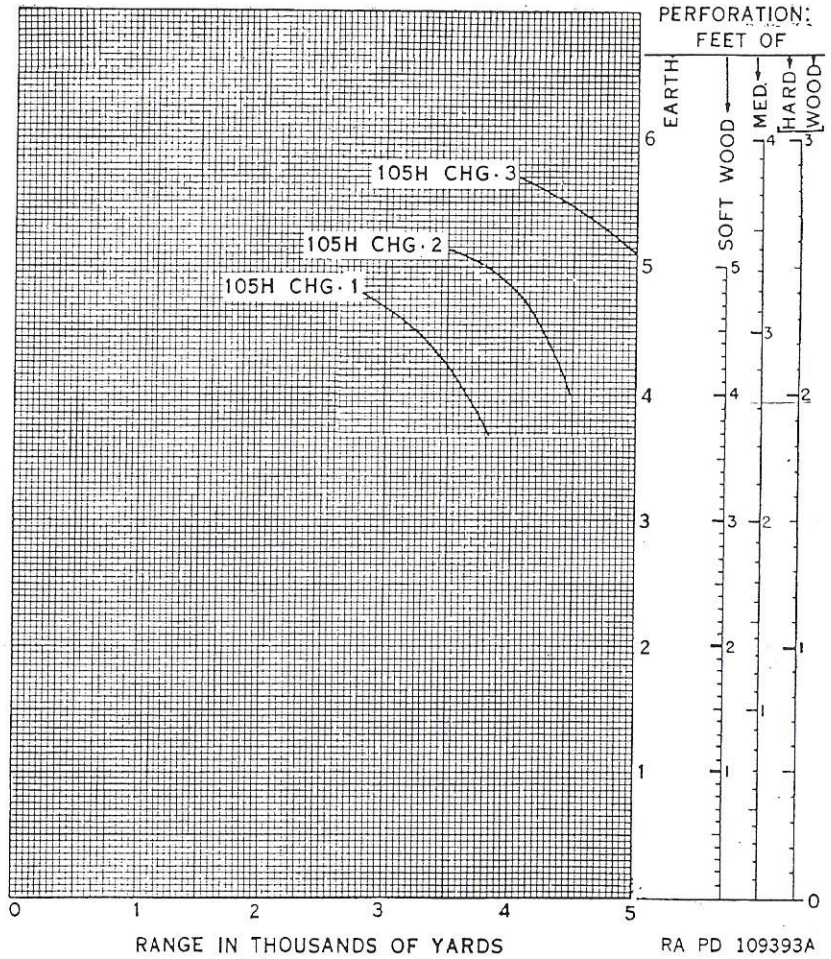
81M chg 4—81-mm mortar M1 firing shell, HE, M56, w/fuze, PD, M53; 4 increments

81M chg 3—81-mm mortar M1 firing shell, HE, M56, w/fuze, PD, M53; 3 increments

81M chg 2—81-mm mortar M1 firing shell, HE, M56, w/fuze, PD, M53; 2 increments

81M chg 1—81-mm mortar M1 firing shell, HE, M56, w/fuze, PD, M53; 1 increment

Figure 145. Perforation of earth and log roofs. High-angle fire. Maximum ranges for 75-mm howitzer and 81-mm mortar.

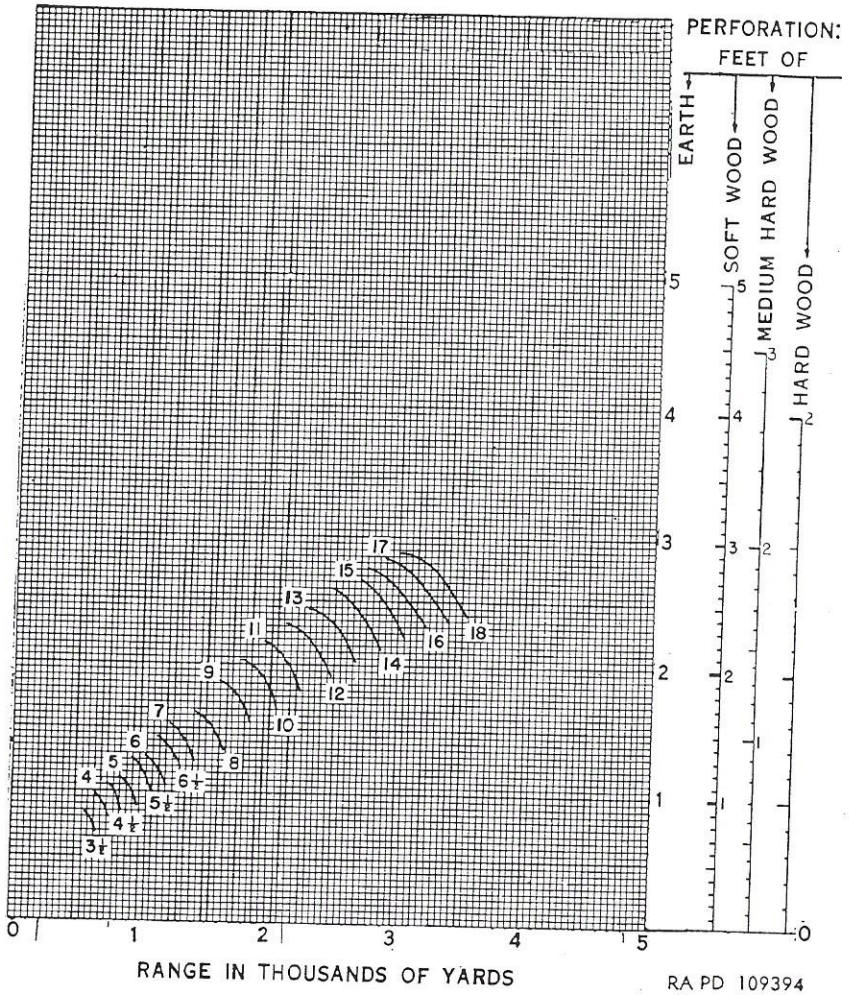


105H chg 3—105-mm howitzer, M2A1, M4, or M3 firing shell, HE, M1, w/fuze, PD, M48 (and mods) or fuze, CP, M78, 0.025 sec delay; charge 3

105H chg 2—105-mm howitzer, M2A1, M4, or M3 firing shell, HE, M1, w/fuze, PD, M48 (and mods) or fuze, CP, M78, 0.025 sec delay; charge 2

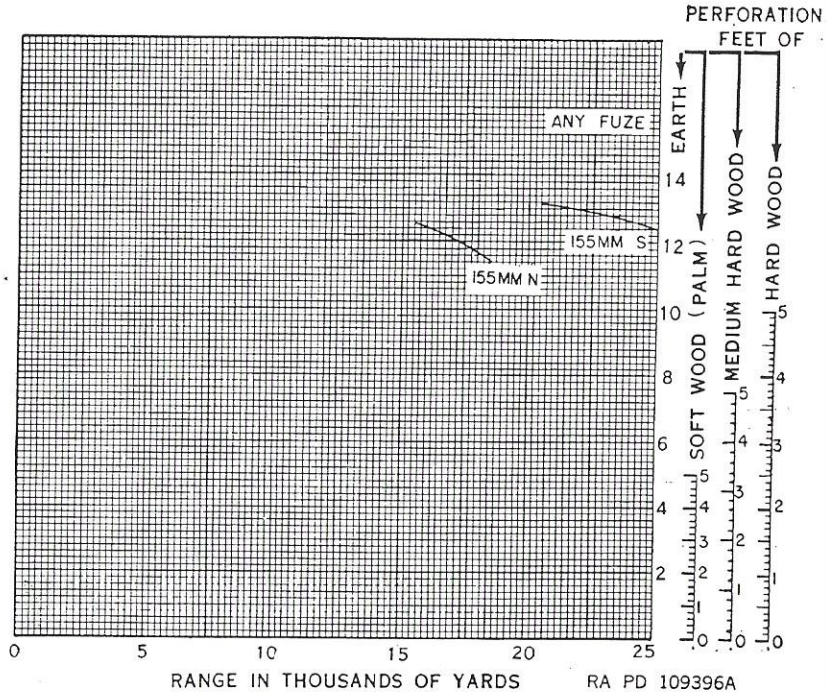
105H chg 1—105-mm howitzer, M2A1, M4, or M3 firing shell, HE, M1, w/fuze, PD, M48 (and mods) or fuze, CP, M78, 0.025 sec delay; charge 1

Figure 146. Perforation of earth and log roofs. High-angle fire. Maximum ranges for 105-mm howitzer.



Note: Index numbers on graph curves refer to number of propellant increments

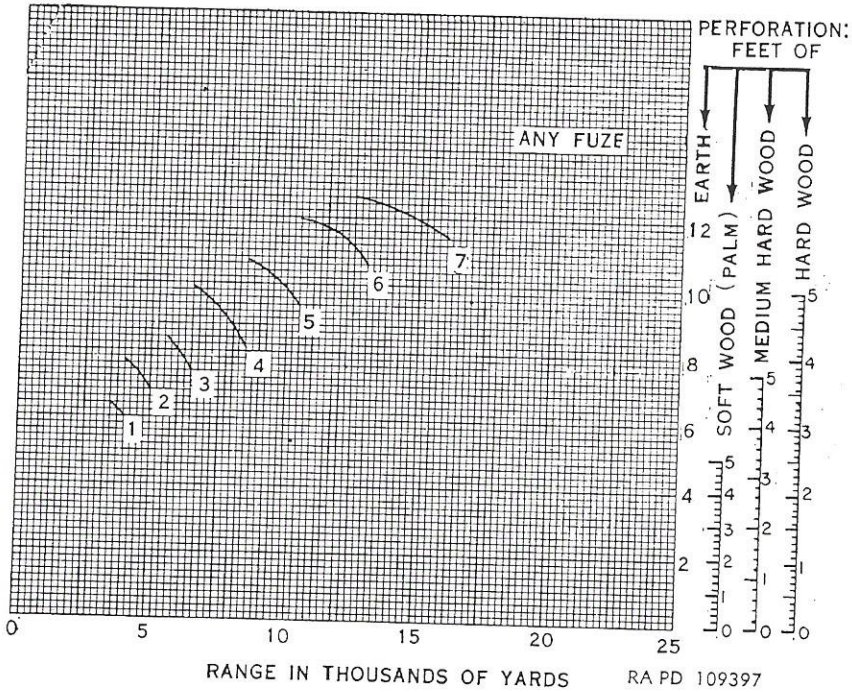
Figure 147. Perforation of earth and log roofs. High-angle fire. Maximum ranges for 4.2-in. chemical mortar, firing HE shell, M3, w/fuze, PD, M4A1.



155-mm N—155-mm gun, M2 firing shell, HE, M101, w/fuze, PD, M51 (and mods) or fuze, CP, M78, 0.025 sec delay; normal charge.

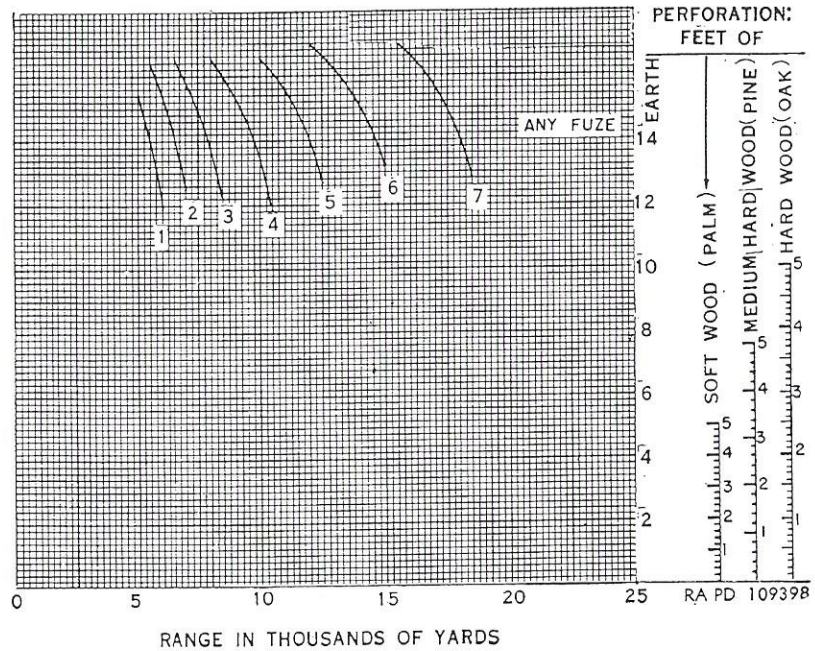
155-mm S—155-mm gun M2 firing shell, HE, M101, w/fuze, PD, M51 (and mods) or fuze, CP, M78, 0.025 sec delay; supercharge

Figure 148. Perforation of earth and log roofs. High-angle fire. Maximum ranges for 155-mm gun M2.



Note: The numbers in the graph refer to the zone numbers of the propelling charge.

Figure 149. Perforation of earth and log roofs. High-angle fire. Maximum ranges for 155-mm howitzer, M1 firing HE, shell, M107, w/fuze, PD, M51 (and mods) or fuze, CP, M78, 0.025 sec delay.



Note: The numbers in the graph refer to the zone numbers of the propelling charge.

Figure 150. Perforation of earth and log roofs. High-angle fire. Maximum ranges for 8-inch howitzer, M2 firing HE, shell, M106, w/fuze, PD, M51 (and mods) or fuze, CP, M78, 0.025 sec delay.

APPENDIX

REFERENCES

1. Publications Indexes

The following publications indexes should be consulted frequently for latest changes or revisions of references given in this appendix and for new publications relating to matériel covered in this manual:

a. Ordnance Supply Catalog Index ..... ORD 2
b. Ordnance Major Items and Combinations, and Pertinent Publications ..... SB 9-1
c. List and Index of Department of the Army Publications. FM 21-6
d. List of War Department Films, Film Strips, and Recognition Film Slides ..... FM 21-7
e. Military training aids ..... FM 21-8

2. Department of the Army Supply Catalogs

a. Projectiles, separate loading, 6-in., 155-mm, 8-in., and 240-mm, for harbor defense, heavy field, and railway artillery, including complete round data ..... ORD 11 SNL P-1
b. Charges, propelling, separate loading, 6-in., 155-mm, 8-in., and 240-mm, for harbor defense, heavy field, and railway artillery .... ORD 11 SNL P-2
c. Projectiles, separate loading, 12-in., 14-in., and 16-in., for harbor defense and railway artillery, including complete round data ..... ORD 11 SNL P-3
d. Charges, propelling, separate loading, 12-in., 14-in., and 16-in., for harbor defense and railway artillery ..... ORD 11 SNL P-4
e. Ammunition for antiaircraft artillery ..... ORD 11 SNL P-5
f. Ammunition, fixed and semifixed, including subcaliber, for pack, light and medium field, aircraft, tank, and antitank artillery, including complete round data..... ORD 11 SNL R-1
g. Projectiles and propelling charges, separate loading, for medium field artillery, including complete round data ..... ORD 11 SNL R-2
h. Bombs, aircraft, all types ..... ORD 11 SNL S-1
i. Fuzes and miscellaneous explosive components for aircraft bombs ..... ORD 11 SNL S-2
j. Fin assemblies and miscellaneous inert components for aircraft bombs ..... ORD 11 SNL S-3
k. Grenades, hand and rifle, and fuzing components ..... ORD 11 SNL S-4
l. Rockets, all types and components ..... ORD 11 SNL S-9

3. Explanatory Publications

a. Ammunition, General ..... TM 9-1900
b. Ammunition, General ..... SB 9-AMM 1
c. Ammunition Inspection Guide ..... TM 9-1904
d. Ammunition, Supply Within Continental United States ..... SB 9-AMM 6
e. Artillery Ammunition ..... TM 9-1901
f. Bombs for Aircraft ..... TM 9-1980
g. Dictionary of United States Army Terms .. TM 20-205
h. Elements of Ordnance, by Thomas J. Hayes (John Wiley and Sons, Inc.)
i. Explosives and Demolitions ..... FM 5-25
j. Field Artillery and Field Mortar Ammunition OFSB 3-3
k. Hand and Rifle Grenades, Rocket, AT, HE, 2.36-inch ..... FM 23-30
l. Military Explosives ..... TM 9-2900
m. Naval Ordnance, by Officers of the U. S. Navy (U. S. Naval Institute, Annapolis, Md.)
n. Qualification in Arms and Ammunition Training Allowances ..... AR 775-10
o. Selection of Bombs and Fuzes for Destruction of Various Targets ..... FM 1-110
p. Range Regulations for Firing Ammunition for Training and Target Practice ..... AR 750-10
q. Rockets ..... TM 9-1950
r. Small Arms Ammunition ..... TM 9-1990
s. Ammunition, Restricted or Suspended ..... SB 9-AMM 2

4. Firing Tables

a. An index of firing tables, trajectory charts, and trajectory diagrams, for small arms, field, and antiaircraft matériel is maintained in ..... FM 21-6
b. Bombing Tables.
The index to bombing tables contains a list of all current bombing tables and changes thereto BTI-3
Introduction to bombing tables BT-2
c. Rocket Tables.
Firing tables for ground fired rockets are indexed in ..... FM 21-6
Firing tables for aircraft rockets are listed in BTI-3

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